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BASIC PHYSICS

FOR SECONDARY SCHOOLS

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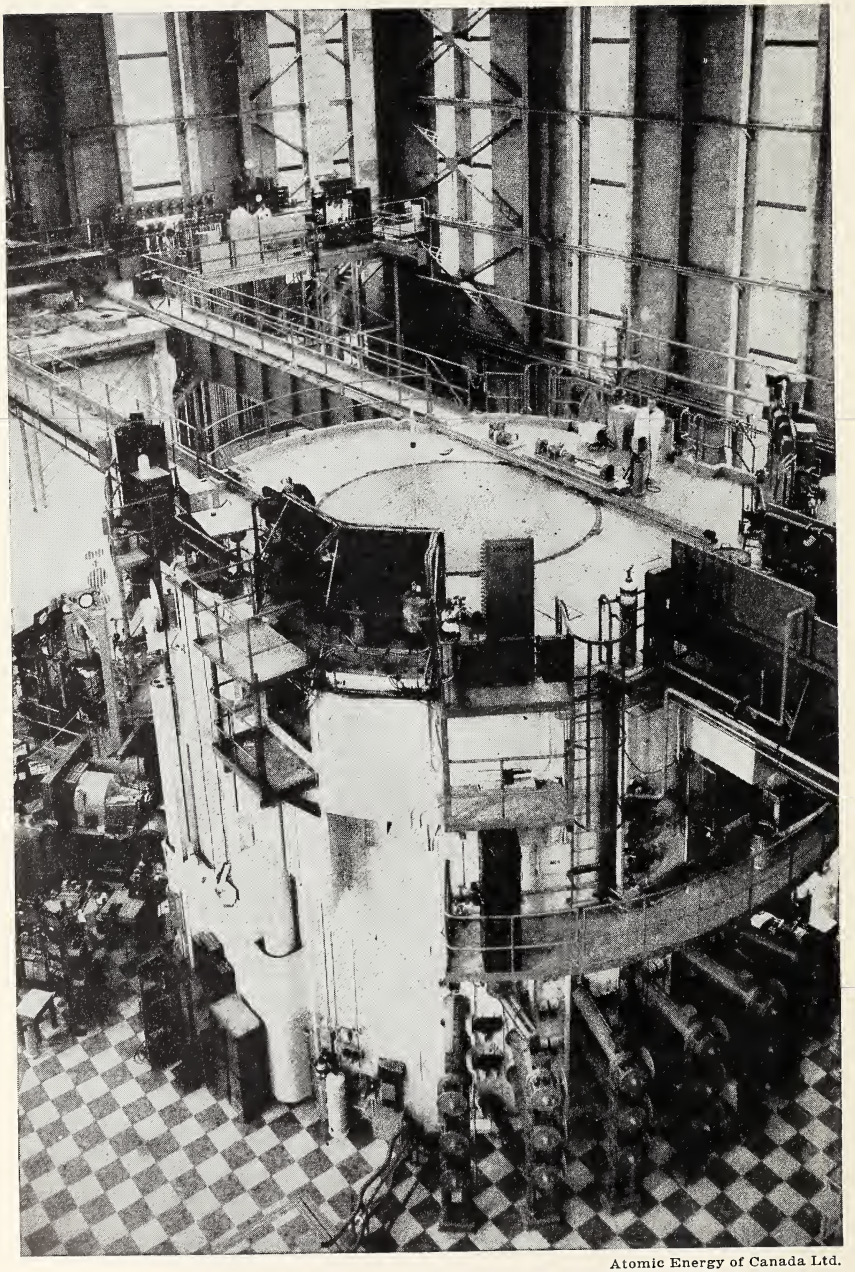
BASIC PHYSICS

FOR SECONDARY SCHOOLS



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BASIC PHYSICS

FOR SECONDARY SCHOOLS

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PREFACE

The most striking fact in the modern world is the development of our knowledge of physics. All machines and appliances result from the application of that knowledge. This text attempts to give an insight into a few fundamentals of the subject and an understanding of some of their applications. These have been presented in a clear, concise and yet sufficiently comprehensive manner to meet the needs of both student and teacher. Specifically designed to cover the Ontario Course of Study in Grade XI Physics, the text includes supplementary material which enables it to meet most of the requirements of courses of study in physics in other provinces, and at the same time makes provision for the above average student.

Grade XI Physics should be an experimental course and each unit has therefore a concluding chapter of experiments. The apparatus suggested is simple enough to enable most of these to be carried out by the pupils themselves. We believe this special feature of the text will encourage a scientific outlook in pupils and save much valuable time for the teacher.

The need for accuracy and precision in making observations, taking measurements, making calculations and reaching conclusions, is constantly emphasized. To aid in this, a section is included on accuracy of measurement and the use of approximate numbers. Pupils are expected to work all mathematical problems, including the results of their experiments, in accordance with these principles. Sample solutions for each new type of mathematical problem are given throughout the text. In these, as well as in the answers provided in the back of the book, the rules for significant digits have been consistently observed.

Among other features which the authors hope will be useful to teachers and pupils alike, two may be singled out for mention: All explanations and diagrams relating to electricity are based on the modern concept of electron flow. Secondly, all right-hand pages are clearly marked with section numbers so that desired information may be quickly found. While the authors believe that these and many other features will recommend the book to its users, they recognize that improvements and revisions will be necessary in future editions. To this end they cordially invite comments and suggestions from teachers who have used the book in their classrooms.

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We acknowledge gratefully the efforts of those friends and colleagues who helped in the preparation of this text. Thanks are also due to the many commercial organizations which provided illustrative material.

In conclusion we have not forgotten what we owe to the patience and understanding of our wives and families.

April, 1957

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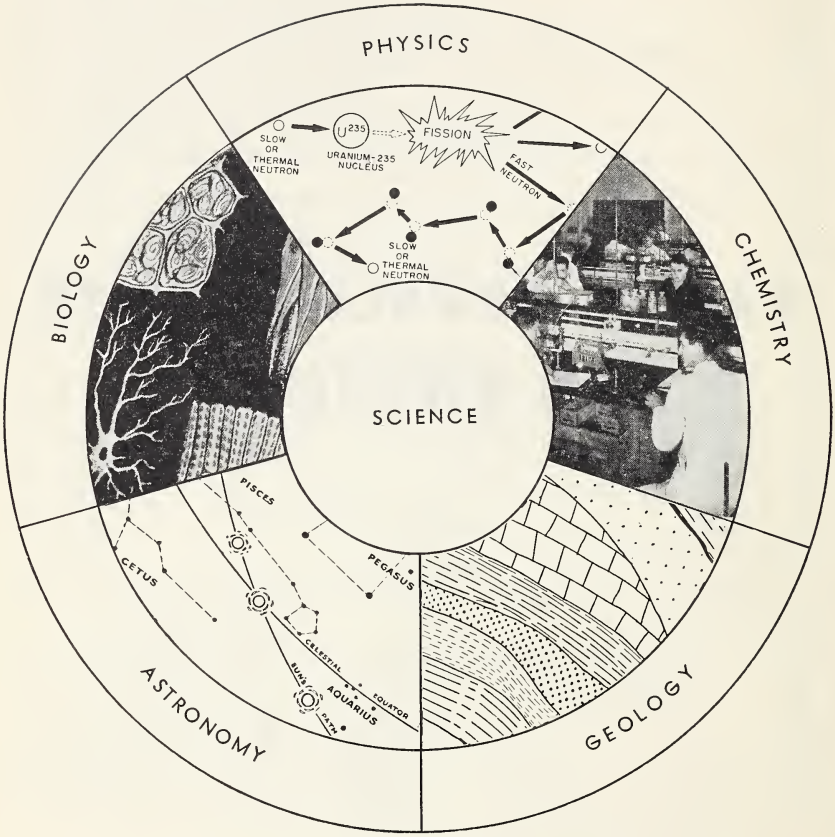
EARLY DEVELOPMENTS IN PHYSICS



THE MAJOR DIVISIONS OF SCIENCE

CHAPTER 1 INTRODUCTION

THE MEANING AND SCOPE OF PHYSICS

So wide is the subject's scope, and so numerous are its developments, that no single statement can convey fully what is meant by the word Physics—except, perhaps, the statement that this is the fundamental science, whose principles form the basis of such other sciences as Biology, Chemistry, Geology, and Astronomy. Its subject matter contains the principles that enable us to understand, as far as we do, the operation of the universe and everything within it, and, by telling us how the forces of nature act, it enables us to control them and put them to work in the service of man. Every time you turn on the taps for a bath, switch on the electric light, phone a friend, or one of the many other things which have come to seem the necessities as well as the luxuries of life, you will be in contact with devices whose invention was made possible by a knowledge of physical laws.

So vast a subject may seem unmanageable; and yet a division of it into all its possible parts would be equally bewildering. And so, for convenience, a division into several major sections, each of which contains many separate subjects, is generally made. These sections are the subjects of the units of this book: Mechanics, Sound, Heat, Light, Electricity and Magnetism, and—in the chapter entitled Modern Developments in Physics—Nuclear Physics.

SOME EARLY DEVELOPMENTS

But before coming to these, let us look at our subject's past.

Theoretical physics may be said to have had its beginning when primitive man first speculated on the causes for the seasons, for day and night, and for the motions of the heavenly bodies, but practical physics did not begin until he invented such simple machines as the lever to lift weights and the wheel to move them. Slow as his progress was, it was from this time of his first applying his physical knowledge, in however fumbling and incomprehending a way, that he could date his emergence from his primitive existence towards what we think of as civilization.

Society followed society, each progressing a little together with man's knowledge of physics. The famous civilizations of Egypt and Greece which, with the rapid expansion of knowledge that accompanied their eager enquiries into the mysteries of the universe, provide us with the first notable names in our story, those of the philosophers, or learned men, like Aristotle, Archimedes and Ptolemy. Archimedes, who is cele-

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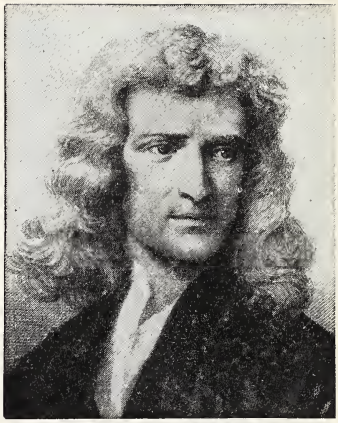
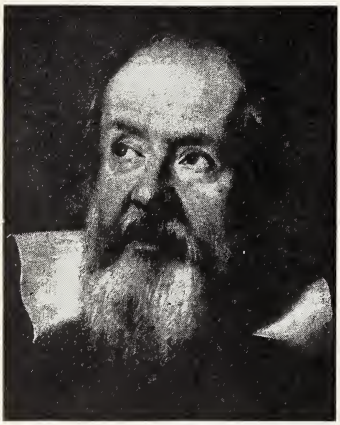
Dr. William Gilbert (1540-1603) Carried out many interesting experiments in magnetism and static electricity.



University of Toronto

Sir Isaac Newton (1642-1727) English mathematician and physicist made many important scientific contributions.



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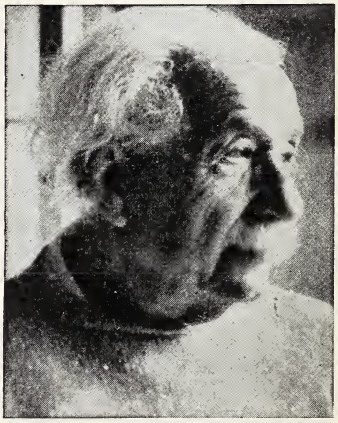
Galileo (1564-1642) Italian physicist, astronomer and mathematician.



Star Newspaper Service

Albert Einstein (1879-1955) American physicist, best known for his theory of relativity.

Fig. 1:1

brated among other things for his laws of buoyancy, is the first man we know of who sought truth by experiment. Aristotle in Greece and Ptolemy in Egypt, on the other hand, relied solely on reasoning and logic for their explanations of natural phenomena and saw no reason for testing their speculations and theories experimentally.

After this first great awakening, little scientific progress was made for centuries and, in general, knowledge remained fixed at the theories of Aristotle. The genius of the Romans was exercised in conquest, government and law rather than in scientific enquiry. After them, during the Middle Ages when civilization was struggling for existence, it was left to the Arabs to try to preserve what scientific knowledge had been gained, by collecting as many of the writings of the Greeks and other peoples as possible. In north-western Europe, an Englishman, Roger Bacon (1214-1294), did indeed foresee many future scientific developments, but he was kept from making his theories known by fear of the Church which all this time fiercely opposed any scientific advance.

The shackles of the Church's opposition and the rigid adherence to Aristotle's scientific theories were not in fact broken until the sixteenth and seventeenth centuries when the great rebirth of intellectual activity which we call the Renaissance occurred. It is from this time that we date the beginning of modern experimental physics. Dr. Gilbert (1540-1603), Physician to Queen Elizabeth I, made the first experimental study of magnetism, and Galileo (1564-1642), experimentally established the laws of falling bodies. Sir Isaac Newton (1642-1727), who had perhaps one of the most brilliant and penetrating minds before the time of Einstein, developed the basic laws of mechanics, studied light and astronomy, and invented the very useful branch of mathematics called calculus.

The century and more which followed Newton's death saw established all the main branches of physical science which were referred to in the first section, with the exception of nuclear physics. The work of Ampere, Volta, Ohm, and Faraday on electricity was so important that their names are still used to designate the units of measurement of electrical energy.

Most important for the nineteenth century, the period in which physical investigation reached a climax, was the work on heat which gave rise to the idea of the basic importance of energy as the source of all activity. All physical phenomena, it was found, represent transformations of energy, exchanges of energy, or the interaction of objects that possess energy. The general applicability of this concept of energy is what has led to the rather incomplete definition of physics as "the subject which deals with forces and forms of energy in our environment". Then, later in the nineteenth century, the study of energy reached its culmination, transforming the whole appearance of physics, when it was realized that energy is transmitted from place to place by a wave motion and that the various branches of physics are simply different energy phenomena transmitted in this manner. This realization of the wave motion of energy provides the beginner in physics with some hope at least of unity in a subject that appears to be greatly diversified.

On the practical side, the work of the nineteenth century laid the foundations, among other things, of almost all our modern means of communication, transportation and power production, both by electricity and atomic energy. In this last respect science seems to have provided a solution for the problems which its own developments were raising. Many

of these developments made for new occupations, better working conditions, a higher level of health and a longer span of life, with a consequent increase in world population. The resulting larger demand for every kind of commodity necessitated such a rapid consumption of energy that the available reserves of the world began to dwindle rapidly and scientists had to explore, as they are still exploring, ways and means of avoiding disaster a few generations hence. As it happened, hope for the future was provided as early as 1905 by Dr. Albert Einstein (1879-1955) when he estimated the energy resources of the atom. Recently that hope has been translated into reality as physicists have learned to release and control this tremendous store of energy.

THE METHOD OF SCIENCE

Dr. Gilbert, the first great English exponent of the principles of magnetism, spoke defiantly of speculative scientists and traditionalists as "men of acute intelligence, without actual knowledge of facts who in the absence of experiment, easily slip and err". Thus were condemned most of the early philosophers and some later ones who supported such false beliefs as an earth-centred universe, the caloric theory of heat, and the two-fluid theory of electricity. Thus also was initiated the new method of scientific investigation, the Scientific Method, which has brought about the spectacular developments which mark our civilization, and of which it can be proud.

This method has been defined as the method of organized and critical common sense, a way of thinking that has been used by the successful farmer, craftsman, business or professional man from time immemorial. It is the method used in all problem solving whether in science or daily life. Its steps are depicted in Fig. 1:2 and are as follows:

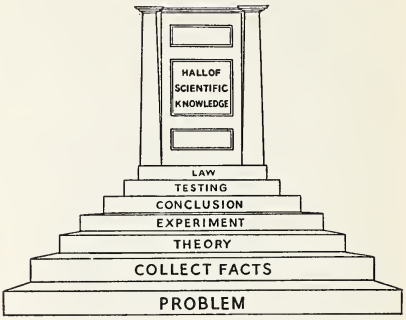


Fig. 1:2 Seven steps to knowledge.

Step 1. There is a question or a problem without an answer.

Step 2. The investigator collects all the facts he can about the problem.

Step 3. In the light of what he now knows, he proposes a theory or possible explanation.

Step 4. To test the theory, an experiment is devised, which, if successful, is repeated to determine whether or not a definite answer can be proposed.

Step 5. The answer is enunciated.

Step 6. This answer or conclusion is tested experimentally to find out whether it will always be true. If it is not always true, it is rejected and a fresh start is made.

Step 7. If the answer is found always to hold true, it becomes a law in the vast body of scientific knowledge and, as such, it may be used to help make further discoveries.

UNIT I

MECHANICS

E. G. L. Wetmore

The Angus L. Macdonald Bridge, Nova Scotia. What Laws of Mechanics Would Apply Here?

CHAPTER 2 MEASUREMENT

2 : 1 SYSTEMS OF MEASUREMENT

As civilization developed and life became more complex, with man planting crops, trading goods or purchasing property, it became essential for him to have some means of measuring length, area, volume, mass and time. The daily movements of the earth, with the resulting apparent motion of the sun and stars, provided a ready-made device for measuring time, but the measurement of the other dimensions could not be managed so naturally.

Man's first systems for measuring them, however, were, though imprecise, very convenient. Measurements of length were based upon parts of the human body (Fig. 2:1). Measurements of weight were often made by using crude scales in which the object to be weighed was balanced against stones or seeds of

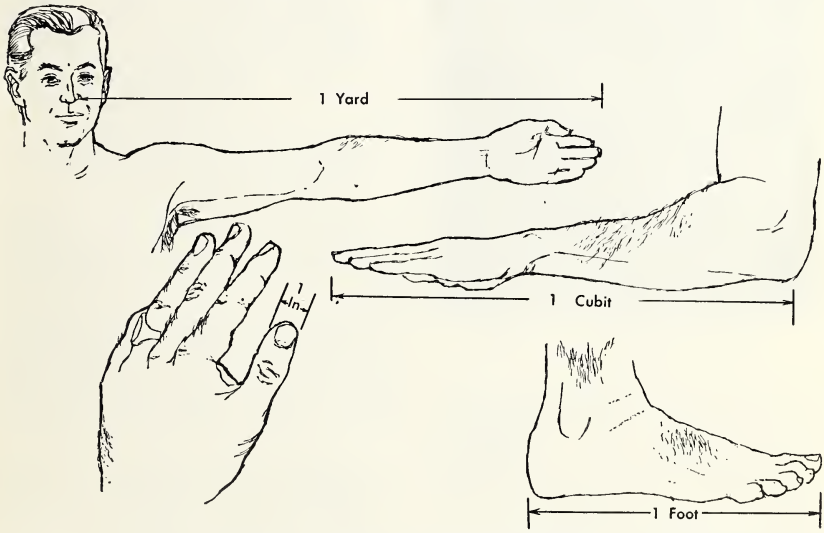


Fig. 2:1 Primitive Measuring Devices.

grain. The convenience of these units is obvious. In measuring a board a man would not have to hunt for a ruler, but would have used his hand or arm. However, in one fundamental respect, these early units were unsatisfactory. They were not standard or uniform.

Moreover, with the beginnings of science and the growth of technology from the invention of the first simple machines, as we have seen, the need for definite and accurate systems of measurement became imperative. Since the aim of science is to describe the facts of experience as simply, as completely, and as accurately as possible, measurement is the very basis of it. Physics is that

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Fig. 2:2 Scientist at work.

branch of science which is specially concerned with the means of measurement —which is why physics is called an "exact science", and why the other divisions of science depend, in varying degrees, on its special techniques.

What are needed, then, are standard units of measurement, units, that is, which are generally acceptable, and preferably units which can be easily and accurately reproduced at any time. Yet,

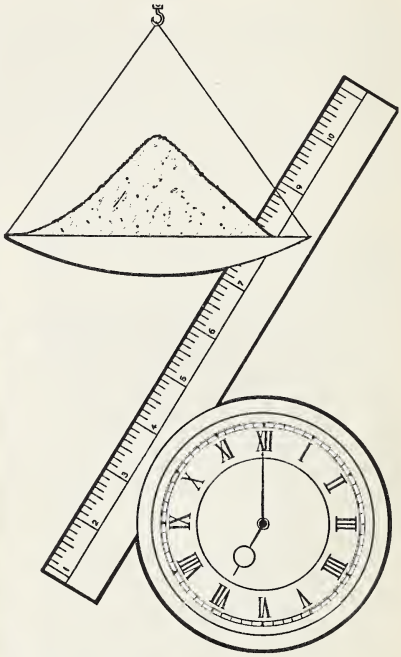


Fig. 2:3 The Three Measurable Magnitudes—Length, Mass and Time.

to define new standards for every type of quantity to be measured would lead to a large collection of unrelated constants.

In order to simplify the scheme of measurement, all units have been brought into relation to three measurable magnitudes, length, mass, and time, which form a basis for all measurements.

SYSTEM	LENGTH	MASS	TIME
English	*Foot*	*Pound*	*Second*
Metric	*Centimetre*	*Gram*	*Second*

There are two systems of units in common use, the British, or foot-pound-second (F.P.S.) system, and the Metric, or centimetre-gram-second (C.G.S.) system. The history of the development of these systems of measurement is very interesting, but unfortunately cannot be given here. The interested student can find it in any good reference encyclopedia.

All the world except the two great English-speaking groups, the British Commonwealth of Nations, and the United States of America, has adopted the metric system of measurement. The metric system is extremely simple, being nothing more nor less than the application of the decimal number system to measurements. Measurements of length and mass begin with a basic unit, the next larger unit being ten times as large, the next smaller unit one-tenth as large, and so on. To convert from one unit to another simply consists in shifting the decimal point one place to the left or right, e.g., 123 metres = 12.3 dekametres, or 1230 decimetres. The relationship of each larger or smaller unit to the basic unit is shown by the prefix to its name. (See the table of prefixes above.) Thus a centimetre is one-hundredth of a metre, (centi = 1/100), while a kilometre is one thousand metres (kilo = 1000). Moreover, the metric system has continuity in that the unit of mass is related to the unit of length. (See definition of "gram" in the next section.) The British system of weights and measures is much more cumbersome and difficult, both because of the heterogeneous groups of multipliers used, and because of the unrelated units of mass and length.

Since the metric system has such decided advantages over the British system, it is used almost exclusively in the scientific field. While this system is legal in both the United States of America and the British Commonwealth of Nations, its common adoption in these countries is prevented in large measure by habitual use of the older system, and by the large amount of industrial machinery already geared to the British system. The student of science is well-advised to master the metric system thoroughly since a working knowledge of it is essential to a proper understanding of many scientific principles that follow.

TABLE OF PREFIXES

Latin	*Greek*
Milli = 1/1000	Deka = 10
Centi = 1/100	Hecto = 100
Deci = 1/10	Kilo = 1000

I : 2 UNITS OF MEASUREMENT

(a) Length

The British system of units is based on the standard yard, which is the distance at 62°F., between the centres of two fine lines engraved on gold studs sunk in a bronze bar. It is kept in the Standards Office in London, England, and a copy of it is preserved in the Department of Inland Revenue at Ottawa. The metric unit of length is the metre (Fig. 2:4), which is the distance at 0°C., between the centres of two lines traced on a platinum-iridium bar, kept at the International Bureau of Weights and Measures, in Sèvres, near Paris. A copy of it is also kept in Ottawa.

TABLE OF LINEAR MEASURE

British Units

12	inches (in.)	= 1 foot (ft.)
3	feet	= 1 yard (yd.)
5½	yards	= 1 rod (rd.)
320	rods	= 1 mile (mi.)

Metric Units

10 millimetres (mm.)	= 1 centimetre (cm.)
10 centimetres	= 1 decimetre (dm.)

10 decimetres	=1 metre (m.)
10 metres	=1 dekametre
10 dekametres	=1 hectometre
10 hectometres	=1 kilometre (km.)

1 inch = 2.54 centimetres

In the measurement of area and volume, the units used are derived from linear units. Since a surface has two

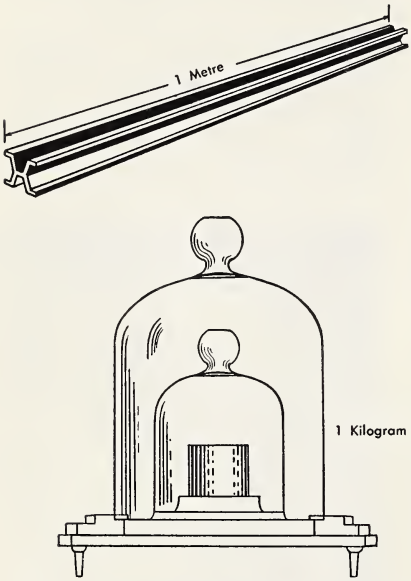


Fig. 2:4 Standard Metric Units—The Metre, The Kilogram.

dimensions, length and width, the units of area are expressed in square measure. Since an object has three dimensions, length, width and height, the units of volume are cubic measure. From the previous tables of linear measure, the student should be able to prepare tables of square measure and of cubic measure in both British and metric units.

One unit for measuring volume, the **litre,** deserves emphasis above the others as it is frequently used in scientific work. For practical purposes it has the same volume as a cubic decimetre or 1000 cubic centimetres.

1 litre = 1 cubic decimetre (cu. dm.)
= 1000 cubic centimetres (c.c.)
= 1000 millilitres (ml.)
= 1.76 pints.

Note. The ml. and c.c. may be used interchangeably for our purposes, even though the two are not absolutely identical.

(b) Mass

The unit of mass in the British system is the **pound.** The standard pound is the quantity of matter in a cylinder of pure platinum about 1.35 inches high and 1.15 inches in diameter, kept in the Bureau of Standards in London, England. In the metric system, the unit of mass is the **kilogram** (Fig. 2:4), which is the mass of a piece of platinum-iridium kept at Sèvres, France. Originally it was intended to be the mass of 1000 cubic centimetres (1 litre) of water at 4°C. and at standard atmospheric pressure (i.e., 760 mm. of mercury). The gram is one-thousandth part of a kilogram, and is the mass of one cubic centimetre of water at 4°C. and at standard atmospheric pressure.

COMMON UNITS OF MASS

British Units

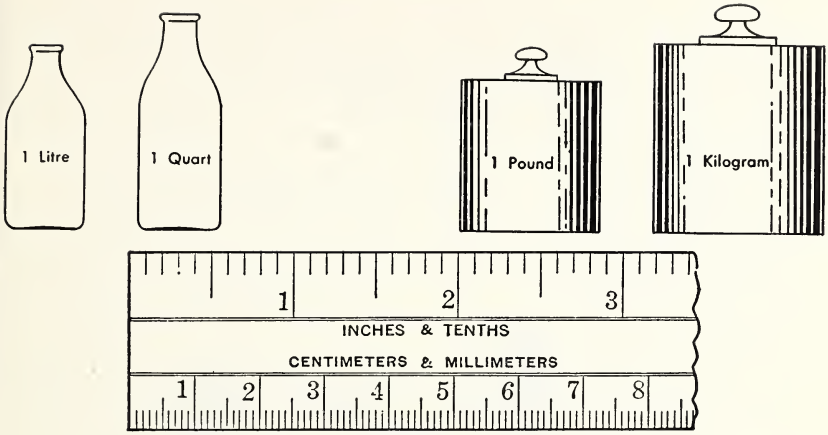
16 ounces (oz.)	= 1 pound (lb.)
2000 pounds	= 1 ton

Metric Units

10 milligrams (mg.)	= 1 centigram (cg.)
10 centigrams	= 1 decigram (dg.)
10 decigrams	= 1 gram (gm.)
10 grams	= 1 dekagram
10 dekagrams	= 1 hectogram
10 hectograms	= 1 kilogram (kg.)

1 kilogram = 2.2 pounds (approx.)

It should be recalled that although the units for measuring mass and weight are the same, mass and weight are dif-



1 in. = 2.54 cm. 1 kg. = 2.2 lb. 1 Litre = 1.76 pints.

Fig. 2:5 Comparison of British and Metric Units.

ferent. Mass is the quantity of matter in an object and is always constant. Weight is the pull of gravity upon an object and varies with the distance of the object from the earth's centre.

(c) Time

The second is the unit universally used in reckoning time. Like day and night and the seasons, it is determined by the earth's motion. The average time between successive passages of the sun across a meridian is called the mean solar day, and the second is 1/86,400 part of it. In other words, the second is 1/86,400 of the time which the earth takes to make one complete rotation on its axis.

I : 3 CALCULATIONS BASED ON MEASUREMENTS

(a) Accuracy of Measurement

In the experiments at the end of this unit, chapter 5, and throughout the book, you will have opportunities to make measurements and use some of the units mentioned in the previous section. Measurement seems a very accurate operation indeed, but there is a limit to the degree of accuracy that is possible. If a farmer has five hundred baskets of fruit, this is an exact number. When he sells them for fifty cents each he will receive exactly two hundred and fifty dollars, another exact number. In this and all other similar operations involving a number of finite objects, you are dealing with exact numbers.

If, however, you measure the length of your living-room and say that it is fifteen feet long, it is likely to be a little longer or shorter than this. In the same way a door that is thirty inches wide may measure a little more or a little less than this. The limit of accuracy is governed to a large extent by the type of measuring instrument that is used and the care exercised in using it. Figure 2:6 shows a number of instruments used for making measurements. Because all measuring devices have limitations, it follows that all measurements are approximate and calculations based on such measurements, although the

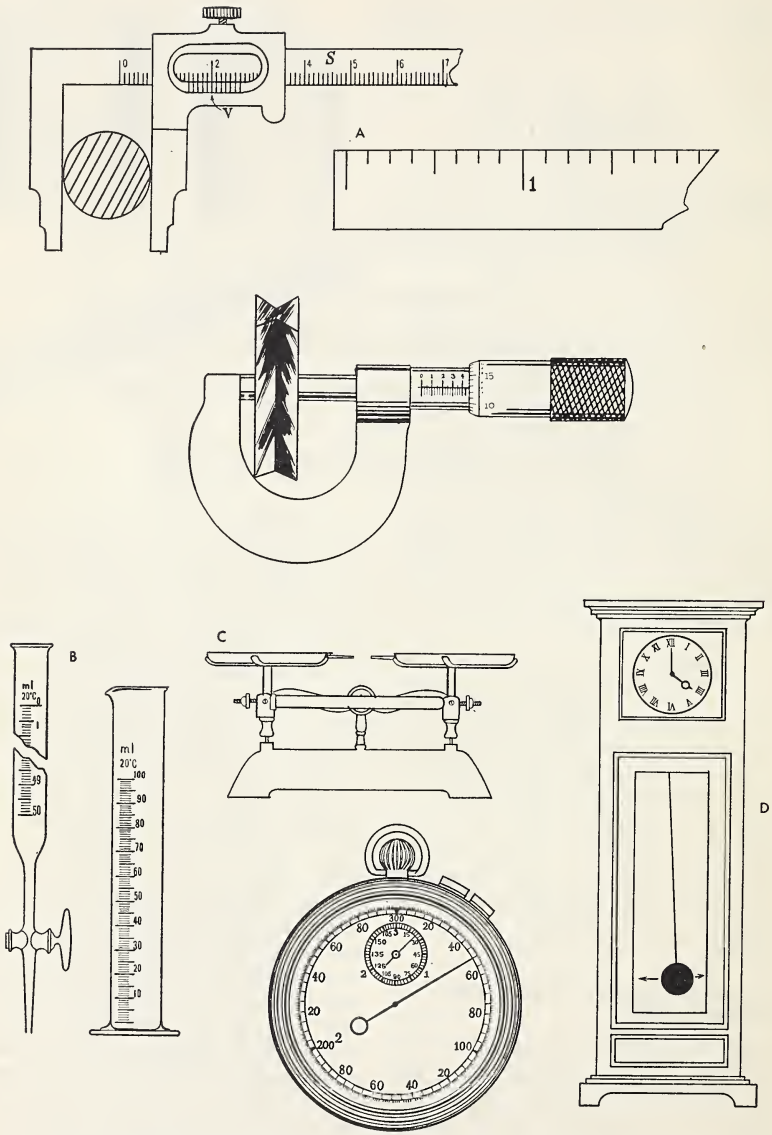


Fig. 2:6 Instruments for Measuring: A Length—Ruler, Calipers, Micrometer; B Volume—Burette, Graduated Cylinder; C Mass—Equal Arm Balance; D Time—Pendulum, Stop-Watch.

mathematical operations are done correctly, give numbers as answers that are not quite perfect. Thus numbers that are derived by measurement are called **approximate numbers.**

(b) Calculations

The aim in calculations is to arrive at an answer that is as accurate as possible but that, at the same time, does not indicate more accuracy than that of the least accurate measuring instrument employed. Thus, if the dimensions of a rectangle are 7.54 cm. by 3.81 cm., the proper area is 28.7 sq. cm., not 28.7274 sq. cm. The latter number expresses measurement with greater accuracy than is possible with the means at our disposal. The reasons will be apparent after studying later paragraphs (page 15).

(c) Approximate Numbers

In all measurement, you must first decide what will be the **limits of accuracy** of your work and then realize that a **possible error** exists in the result. In order to make this small, the possible error is not permitted to exceed one-half of the smallest unit employed in the operation. Thus, in the previous examples, if 1/8 inch were the smallest unit on the measuring instrument used, a possible error of 1/16 inch more or less is found in the answer. Accordingly the length of the room in part (a) would be between 14 feet, 15/16 inch and 15 feet, 1/16 inch and the width of the door would be between 29 15/16 and 30 1/16 inches. Similarly, if the present room temperature is given as 21.5°C., and the thermometer is marked off into 0.1 degree units, the possible error will be .05 centigrade degrees and the actual reading may be between 21.45°C. and 21.55°C. The reading 21.5°C. represents the temperature as accurately as the means of measurement at our disposal will permit. Other examples follow:

Measurement	*Limits of Accuracy*			
55.3 cm.	From	55.25 cm.	up to but not including	55.35 cm.
719 ft.	"	718.5 ft.	" " " " "	719.5 ft.
19.0 ft.	"	18.95 ft.	" " " " "	19.05 ft.
0.0032 in.	"	0.00315 in.	" " " " "	0.00325 in.

To allay the fear that naturally arises over the presence of this possible error, let us calculate what per cent of the whole it represents. The percentage error is possible error divided by the accepted number times 100. Using the first measurement in the preceding table we get:

The percentage error =

$$\frac{55.3 - 55.25}{55.3} \times 100 \text{ or } \frac{55.3 - 55.35}{55.3} \times 100$$

$$= + \frac{.05}{55.3} \times 100 \text{ or } - \frac{.05}{55.3} \times 100$$

$$= + .09\% \text{ or } - .09\%$$

From this, we see that approximate numbers contain an extremely small error. The more precise the measuring device is, the smaller the unit of measurement will be. The smaller the unit of measurement is, the smaller the possible error will be.

(d) How to Deal with Approximate Numbers

1. Significant Digits

When performing a measurement, only those numbers in the measurement that are certain, like the 15 feet, 30 inches, 21.5°C. of previous paragraphs, are recorded. The digits in these numbers

are called the **significant digits** in the result, there being two in the first two numbers above, and three in the third. Mathematicians have laid down certain rules to guide us in working with them. They are as follows:

1. All the digits from 1 to 9 including any zeros between them or after them are significant digits.
2. The position of the decimal is disregarded in determining the number of significant digits.
3. The zeros preceding the first digit are not significant.

SIGNIFICANT DIGITS IN NUMBERS

Number	*Significant Digits*
604	3
60.4	3
6.04	3
0.604	3
0.0604	3
0.06004	4
604.0	4
60.40	4

2. Representing Significant Digits in Large Numbers

Where a number like 600 is correct to one significant digit, it should be written as 6×10^2. To express it as 600 indicates three significant digits. Similarly, the distance from the earth to the sun is correct to only two significant digits and should be written 93×10^6 rather than 93,000,000 miles.

3. Rounding off Approximate Numbers

A number like the value of pi (π), 3.14159, is correct to 6 significant digits. It may be made consistent with measurements having fewer than six significant digits by the process of **rounding-off.** This means dropping the necessary number of digits off the end of a number and adding one to the last remaining digit if the next digit was five or more.

Examples

Rounding-off	*Accuracy*
3.14159	6 significant digits
3.142	4 " "
3.1	2 " "

4. Calculations With Significant Digits

How to carry out mathematical operations with approximate numbers is indicated by the following rules:

1. Addition and Subtraction
   In operations involving addition and subtraction of approximate numbers of which the least precise has N places of decimals, round off the other numbers where possible to N + 1 places and the answer to N places.
2. Multiplication and Division
   In operations involving multiplication and division of approximate numbers of which the least accurate has N significant digits, round off the others where possible to N + 1 digits and the answer to N digits.

Examples

		Method	*Result*
1. Add	2.0149	Round off all	2.015
	3.02864	to three decimals	3.029
	1.239	where possible.	1.239
	1.97	Round off answer	1.97
		to 2 decimals.	———
		Total =	8.253
		Proper answer =	8.25

	Method	*Result*
2. Subtract 21.347 from 32.5	As for addition	32.5 21.35 ——— Difference = 11.15 Proper answer = 11.2
3. Multiply 2.1 by 2.56 and by 9.547	Round off all numbers to 3 significant digits. Keep 3 significant digits in all partial products. Round off answer to 2 significant digits.	$2.1 \times 2.56 = 5.376$ Proper product = 5.38 $5.38 \times 9.55 = 51.3790$ Proper answer = 51.
4. Divide 96.568 by 7.02	As for multiplication	$\frac{96.57}{7.02} = 13.75$ Quotient = 13.75 Proper answer = 13.8

On page 13 we multiplied 7.54 by 3.81, getting 28.7274 for an answer. However, as the multiplier and multiplicand are correct to three significant digits only, 28.7 is the proper answer. You may wonder about the usefulness of the above material, but be assured that the method is used daily by scientists and mathematicians whose work has contributed so much to each modern development and invention.

(e) Applying Approximate Numbers in Elementary Physics

The diameter of a cylindrical solid is 2.50 cm. and it is 10.04 cm. long. ($\pi = 3.1416$). Its mass is 280.76 gm. Calculate its density.

Radius = 1.25 cm.
Length = 10.04 cm.
$\pi = 3.1416 = 3.142$

Area of the end of the cylinder $= \pi R^2$
$= 3.142 \times 1.25 \times 1.25$
$= 4.910$ sq. cm.

Volume of the cylinder = area of end × length
$= 4.910 \times 10.04$
$= 49.30$ c.c.

The mass given = 280.76 gm.
The proper mass = 280.8 gm.

$\because$ 49.30 c.c. of solid weigh 280.8 gm.

$\therefore$ 1 c.c. of solid weighs $\frac{280.8}{49.30}$
$= 5.695$ gm.

$\therefore$ The density = 5.70 gm. per c.c.

1 : 4 QUESTIONS

A

1. (a) Why is measurement necessary?
(b) Why was it necessary to establish standard units?

2. (a) Name the two systems of measurement and name the fundamental units for each.
(b) What advantages has the metric system over the British system of measurement?
(c) Why is the British system still used in a few countries?

3. (a) What apparatus is commonly used in the laboratory for the measurement of (i) length (ii) mass (iii) time?
(b) Suggest other pieces of apparatus that could be used to measure these fundamental units more accurately.

4. (a) State the number of millimetres, centimetres and decimetres in 1 metre. How many metres are there in 1 kilometre?
(b) Using the above units construct tables of (i) square measure (ii) cubic measure.
(c) Define: litre, millilitre.

5. (a) Distinguish between the mass and weight of an object.
(b) State the number of milligrams, centigrams, decigrams, and grams in 1 kilogram.

6. (a) Why was the apparent motion of the sun adopted as the basis for reckoning time?
(b) Define: mean solar day, second.

7. (a) Distinguish between exact and approximate numbers. Give an example of each.
(b) What gives rise to approximate numbers? Why?

8. (a) What do you mean by possible error?
(b) How do you calculate percentage error?

9. (a) What is meant by significant digits?
(b) State the number of significant digits in each of: 32060, 36.060, 0.32060, .032060, 3×10^3, 3.56×10^5.

10. (a) What is meant by rounding off a number?
(b) Round off the following to two significant digits: 36.7, 34.32, 37.495.

11. (a) State the rules for carrying out the following mathematical operations with approximate numbers: (i) addition and subtraction. (ii) multiplication and division.
(b) Do the following:
(i) $10.3575 + 9.75 - 8.65248$.
(ii) $7.935 \times 2.4248 \div 2.3$.

B

1. (a) Express in cm.: 15.2 m., 38 mm., 6 m. 5 cm. 4 mm.
(b) Express in sq. cm.: 3 sq. m., 236 sq. mm., 6 sq. m. 5 sq. cm. 44 sq. mm.
(c) Express in c.c.: 2.5 cu. m., 2300 cu. mm., 6 cu. m. 50 c.c. 465 cu. mm.

2. (a) Determine the number of inches in 950 mm., 40 cm., 10 dm.
(b) Determine the number of (i) cm. in 1 foot, (ii) km. in 1 mile.
(c) Which is the greater distance, 100 yd. or 100 metres? Express the difference in (i) ft. (ii) cm.
(d) An object is travelling at the rate of 40 miles per hour. Calculate the rate in (i) ft. per sec. (ii) metres per sec. (iii) kilometres per hour.

3. A tank is 50 cm. long, 3 dm. wide, and 150 mm. high.
(a) Calculate the area of a cover

for the tank (i) in sq. cm. (ii) in sq. dm.

(b) Calculate the volume of the tank, and express in (i) c.c. (ii) cu. dm. (iii) litres.

4. (a) What mass of water will the above tank hold (1 c.c. of water weighs 1 gm.)? Express this mass in gm., mg., cg., dg., kg.

(b) Calculate the number of (i) grams in an ounce (ii) kilograms in a ton?

(c) Calculate your own weight in kilograms.

5. A beaker is 20 cm. high and has a diameter of 14 cm. Calculate its volume in (i) litres (ii) millilitres (iii) pints.

6. Using proper "rounding-off" techniques, make the following calculations:

(a) Add $9.75+10.357+76.92+5.674$.

(b) Subtract
(i) 10.357
(ii) 5.674
(iii) 9.75
from 76.92.

(c) Multiply
(i) $2.6\times7.93\times1.732$.
(ii) $77.5\times1.4142\times.0032$.
(iii) $46\times23.55\times0.25$.

(d) Divide
(i) 154 by .11.
(ii) 9.5 by 19.03.
(iii) 134.5 by 15.

CHAPTER 3 DENSITY AND SPECIFIC GRAVITY

I : 5 MEANING OF DENSITY

In ordinary conversation we often say that one substance is "heavier" than another, e.g., iron is "heavier" than aluminum. Obviously we cannot mean that any given piece of iron is heavier than every piece of aluminum, but rather that for pieces of equal size, the iron would be the heavier. In science we use the term density to express the physical difference implied in the above everyday statement, that is, we say that iron has a greater density than aluminum. **Density is defined as the mass of a unit volume of a substance.** The method of determining density is described in chapter 5, experiments 1, 2 and 3.

In stating densities the numerical measure must always be accompanied by suitable units, e.g., gm. per c.c., lb. per cu. ft., etc., according to the units in which the mass and volume of the substance have been measured. It should further be noted that the numerical value of the density of any given substance will depend on the system of units used. Thus, since one gram of water (at its maximum density) occupies a volume of one cubic centimetre (Sec. I:2), the density of water in the C.G.S. system of units is 1 gm. per c.c. In the F.P.S. system, however, a cu. ft. of water is found to weigh 62.5 lb. (approx.), and hence the density of water in this system of units will be expressed as 62.5 lb. per cu. ft. Densities (in gm. per c.c.) of various substances are given in the table on page 21.

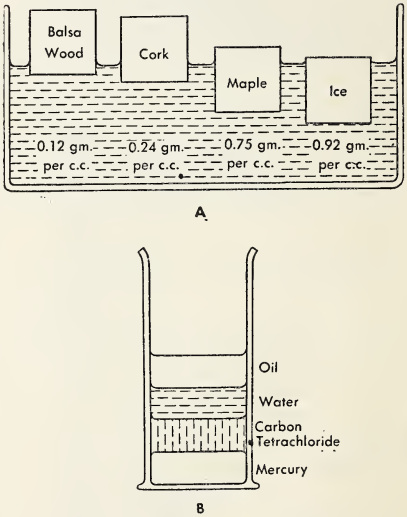
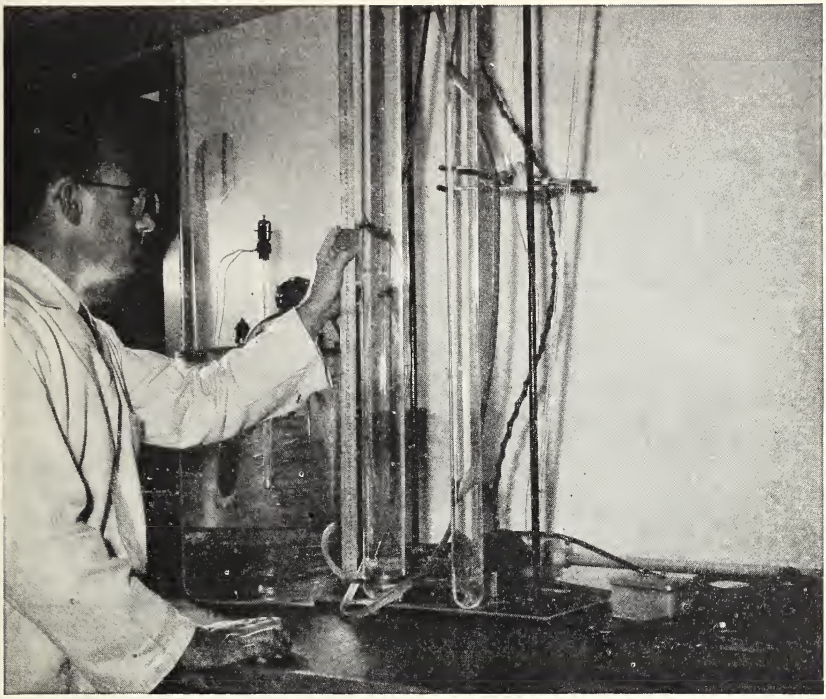


Fig. 3:1 Relative Densities of A— Solids, B—Liquids.

To find the corresponding densities in lb. per cu. ft. the numerical values must be multiplied by 62.5.



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Research Scientist Determining the Density of a Substance by Comparison with Standard Density Floats Suspended in a Solution of Known Density.

We have previously defined mass as the quantity of matter in a body. According to modern theory, matter is comprised of molecules, the molecules of any given substance being identical to each other (Sec. III:2). Hence, differences in density between various substances (Fig. 3:1), are due to the relative masses of their molecules as well as to their spatial arrangement. Variations in the density of a given substance are due to changes which vary the closeness of packing of the molecules.

I : 6 DENSITY OF WATER

It is frequently said that the density of water is 1 gm. per c.c. However, liquids, like solids and gases, expand when heated and contract when cooled with no change whatever in mass. They therefore have different densities at different temperatures.

Careful experiments to show changes in density of water with changes in temperature can be carried out with the aid of the dilatometer shown in Fig. 3:2. If this instrument, filled with water,

is placed in a water bath with a thermometer, and ice slowly added, the volume change can be observed on the

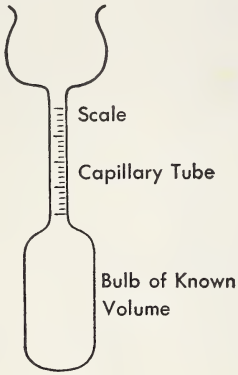


Fig. 3:2 A Dilatometer.

scale, for changes of temperature down to 0°C. The water contracts, i.e., its density increases, until a temperature of

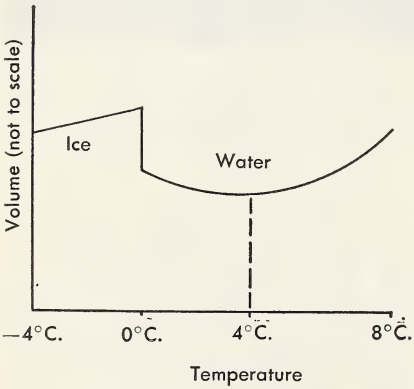


Fig. 3:3 Graph to Show the Effect of Changes of Temperature on the Density of Water.

4°C. is reached. After that, further cooling makes it expand, i.e., its density decreases again. The temperature at which the volume is smallest is the temperature at which the density is the greatest, namely 4°C. We say that water has its maximum density at 4°C. It is at this temperature that 1 cubic centimetre of water has the mass of 1 gram. The changes mentioned above are shown graphically in Fig. 3:3. (Most liquids show a gradual increase in density as the temperature goes down.)

This fact, together with the fact that there is a sudden expansion as water freezes at 0°C. (evidenced by those burst pipes in winter!) is of profound importance in nature. With wintry conditions the coldest layers of a pond or lake are those at the surface, and when these layers freeze the ice so formed remains on the surface because its density is less than that of the water beneath it. Without this unusual behaviour of water the pond would freeze solid from the bottom upwards, greatly to the detriment of all life and to aquatic life in particular.

1 : 7 MEANING OF SPECIFIC GRAVITY

For many purposes, instead of density, it is found more convenient to use the density of a substance relative to that of water. The relationship so obtained is called the **specific gravity** of the substance. It may be calculated in the following way:

$$\text{S.G.} = \frac{\text{density of the substance}}{\text{density of water}}$$

$$\text{S.G.} = \frac{\text{mass of unit volume of the substance}}{\text{mass of unit volume of water}}$$

$$\text{S.G.} = \frac{\text{mass of any volume of the substance}}{\text{mass of an equal volume of water}}$$

Thus specific gravity is a ratio and no units are required. It is simply a num-

ber stating how many times as heavy as water, bulk for bulk, the substance is. Further, it must be evident that the number giving the specific gravity of a substance will be the same whatever the units in which the masses are measured, (Chap. 5, Exp. 4).

In the C.G.S. system the density of water is 1 gm. per c.c., and thus in this system, density and specific gravity are numerically equal. The two terms are not interchangeable, however, although frequently, but wrongly, so used.

I : 8 DENSITY OR SPECIFIC GRAVITY OF VARIOUS SUBSTANCES

The density or specific gravity of solids, liquids and gases is a property that helps us to identify them. Some of these you will have determined experimentally while others will be found in the accompanying table of specific gravities.

Table of Approximate Specific Gravities

Metals			
Magnesium	1.74	Silver	10.5
Aluminum	2.70	Lead	11.4
Zinc	7.15	Mercury	13.6
Tin	7.30	Gold	19.3
Iron (pure)	7.85	Platinum	21.5
Copper	8.90		
Alloys			
Steel	7.0–7.7	Brass	8.4–8.7
Iron (cast)	7.1–7.7	Bronze	8.7–8.9
Miscellaneous Solids			
Cork	0.24	Sand	2.6
Ice (0°C.)	0.92	Pine	0.6
Salt	2.2	Oak	0.8
Liquids			
Gasoline	0.70	Carbon tetrachloride	1.60
Alcohol	0.79	Sea-water	1.01–1.05
Turpentine	0.87	Conc. sulphuric acid	1.83
Gases (at S.T.P.)			
Hydrogen	0.00009	Oxygen	0.00143
Helium	0.00018	Carbon dioxide	0.00198
Air	0.00129	Chlorine	0.00322

Gases, being so light, generally have their densities expressed in grams per litre, instead of grams per cubic centimetre. Also, air or hydrogen (preferably the latter) is used as the standard, rather than water, for purposes of comparison.

1 : 9 QUESTIONS

A

1. (a) Define density and state what two measurements must be made in order to calculate the density of an object.
(b) Calculate the density of a piece of aluminum whose volume is 150 c.c. and whose mass is 405 gm.

2. (a) What effect does an increase in temperature have on the density of most substances? Why?
(b) In what respect may water be said to be an unusual liquid?
(c) Explain why this unusual behaviour of water is important to life.
(d) Why does it require a much longer and more severe period of cold weather to cause a layer of ice to form on deep bodies of water than to form on shallow bodies?

3. (a) Define specific gravity and state clearly what is needed to find the specific gravity of an object.
(b) Calculate the specific gravity of a substance whose volume is 20 c.c. and whose mass is 160 gm.

4. (a) Distinguish between density and specific gravity.
(b) What relationship exists between the specific gravity of a substance and its density?
(c) What is the specific gravity of the aluminum in **1.** (b)?

B

1. Calculate the density of a rectangular solid 25 cm. long, 15 cm. wide, 3 cm. thick, whose mass is 5625 gm.

2. Find the mass of 75 ml. of a liquid whose density is 0.70 gm./ml.

3. Find the volume of an object whose mass is 750 gm. and whose density is 2.80 gm./c.c.

4. Find the density of water if 15 cu. ft. weigh 937.5 lb.

5. Find the mass of 20 cu. ft. of material whose density is 3.2 lb./cu. ft.

6. Find the volume of an object whose mass is 42.7 lb. and whose density is 2.10 lb./cu. ft.

7. Find the specific gravity of a substance whose mass is 148.5 gm. and whose volume is 30.5 c.c.

8. The specific gravity of a substance is 1.85. What volume of it weighs 100 gm.?

9. Find the mass of 0.5 litres of a liquid whose specific gravity is 1.6.

10. Find the specific gravity of a substance whose mass is 3.2 lb. and whose volume is .75 cu. ft. (Density of water is 62.5 lb. per cu. ft.)

11. The specific gravity of a substance is 2.7. What volume of it will weigh 100 lb.?

12. Find the mass of 3.2 cu. ft. of material whose specific gravity is 8.9.

13. An irregular object has a mass of 72.6 gm. On placing it in water in a graduated cylinder the level rises from 12.0 ml. to 21.5 ml. Calculate its density.

14. A specific gravity bottle weighed 24.20 gm. when empty, 67.81 gm. when filled with turpentine and 74.20 gm. when filled with distilled water. What is the specific gravity of the turpentine?

15. A flask weighs 8.8 gm. when empty, 33.6 gm. when filled with water and 28.6 gm. when filled with alcohol. Find the specific gravity of the alcohol.

16. The density of a salt solution is 1.20 gm. per ml. If a flask weighs 12.6 gm. when empty and 62.8 gm. when filled with water, how much will it weigh when filled with the solution?

17. The composition of brass is 75% copper and 25% zinc by volume. Calculate its density.

18. An alloy of tin and lead has a specific gravity of 10.6. Calculate the proportion of tin present in the alloy (a) by volume (b) by weight.

19. A piece of wax whose real specific gravity is 0.96 has an apparent specific gravity of 0.92 owing to a bubble of air being enclosed in it. The volume of the whole is 10.0 c.c. Find the volume of the air enclosed, assuming the weight of the air to be negligible.

20. A piece of metal 11.2 cm. long, 4.5 cm. wide and 1 mm. thick, has a mass of 30.2 gm. Find its density.

21. Calculate the density of a cylinder whose length is 5.2 cm., diameter is 12 mm., and whose mass is 58 gm.

22. Calculate the density of a sphere whose radius is 1.4 cm. and whose mass is 100 gm.

23. A cube of ice whose side is 4 cm. is allowed to melt. The volume of the water is found to be 58.2 ml. Find the density of ice.

24. Four solutions of salt, of densities 1.12, 1.17, 1.19 and 1.20 gm. per c.c., are mixed together in the proportion 1:2:3:4 by volume. Find the density of the mixture.

CHAPTER 4 BUOYANCY

1 : 10 INTRODUCTION TO BUOYANCY

We are all familiar with the fact that things seem lighter under water. Those of us who have helped to build a dock know that a large stone which can only be raised with difficulty when out of the water may be raised quite easily when under water. Similarly, we find that

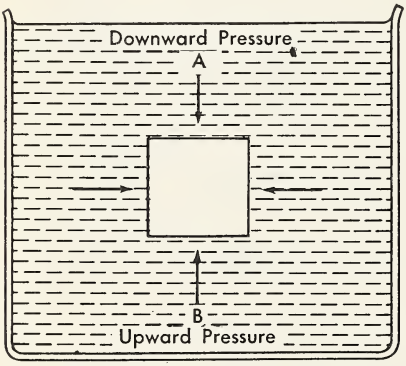


Fig. 4:1 Explanation of Buoyancy.

an anchor becomes heavier on emerging from the water. In general then, bodies immersed in water (or in any fluid) appear to lose some of their weight. This is, of course, due to the fluid exerting a buoyant force or lift on them.

The reason why fluids exert a buoyant force will be apparent after a consideration of the forces that water exerts on an object immersed in it (Fig. 4 : 1). The water exerts a downward pressure upon the top surface of the object, and an upward pressure upon the bottom. Because the bottom of the object is deeper in the liquid than is the top, and because pressure increases with depth, the upward pressure upon the bottom surface will exceed the downward pressure upon the top surface. There will, therefore, be a net upward pressure upon the block. It is this upward force that accounts for the apparent lightness of an object when immersed in the water. The same principle applies to all bodies immersed in any liquid or gas.

Archimedes (287-212 B.C.), a Greek mathematician and inventor, was the first to study the buoyancy of liquids and to enunciate an important principle connected therewith. The story is told that Hiero, king of Syracuse, had sent his jeweller a known mass of gold to be made into a new crown. When the crown was delivered and tested it was found to have the right weight, but there was a suspicion that some silver had been substituted for gold in the interior of the crown. Consequently Archimedes was commissioned to determine whether or not the crown was pure gold, at the same time being instructed not to mar the crown in any way.

Archimedes puzzled over this problem at great length. All that he had to work

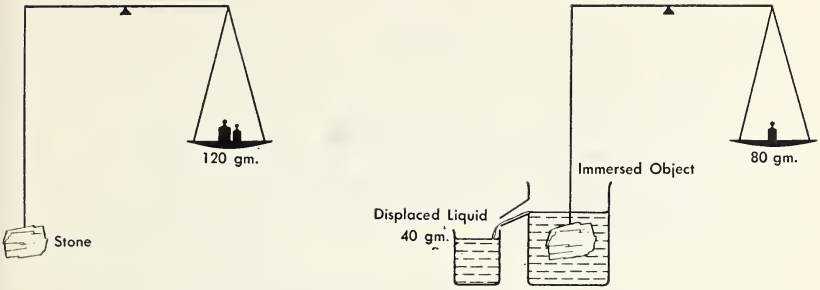


Fig. 4:2 Archimedes' Principle.

with was the well-known fact that an object is easier to lift when immersed in water than when on land.

One day as he hopped into his bath, which had been filled brimful of water, he caused a considerable quantity to overflow onto the brick floor, and he was suddenly struck by the idea that the weight he lost on submerging was equal to that of the water which overflowed. He was so excited by this discovery, so the story goes, that he ran home unclothed shouting, *"Eureka! Eureka!"* ("I have found it! I have found it!")

As you study the principle that Archimedes enunciated, see if you can suggest the experiment that Archimedes probably performed to determine whether or not the crown was pure gold.

I : 11 ARCHIMEDES' PRINCIPLE

The experiment to demonstrate Archimedes' Principle (Chap. 5, Exp. 5, 6) should be studied carefully in conjunction with the following statements:

1. When a body is immersed in a liquid it displaces some of the liquid to make room for itself. Note that the volume of the liquid displaced is equal to the volume of the object.
2. The body is buoyed up by the liquid and therefore seems to weigh less than it does in air.
3. This loss in weight is exactly equal to the weight of the liquid displaced (Fig. 4:2).

Archimedes' Principle, therefore, may be stated as follows: An object, when immersed in a liquid, loses in apparent weight an amount equal to the weight of the liquid displaced.

or an alternative statement is:
The buoyant force of a fluid (liquid or gas) upon an object immersed in it, is equal to the weight of the fluid displaced.

Examples

1. A rectangular piece of metal, 15 cm. long, 6 cm. wide and 3 cm. thick, weighs 2700 gm. in air. Find its weight when immersed in water.

Weight of object in air	= 2700 gm.
Volume of object	= 15 × 6 × 3 = 270 c.c.
Volume of water displaced	= 270 c.c.
Weight of water displaced	= 270 gm. (Density of water = 1 gm./cc.)
∴ Weight of object in water	= 2700 — 270 (Archimedes' Principle)
	= 2430 gm.

2. Find the weight of the object in example 1, if it were immersed in carbon tetrachloride (S.G. = 1.60).
   Weight of object in air = 2700 gm.
   Volume of object = 15 × 6 × 3 = 270 c.c.
   Volume of carbon tetrachloride displaced = 270 c.c.
   1 c.c. of carbon tetrachloride weighs 1.60 gm. (S.G. = 1.60)
   ∴ Weight of carbon tetrachloride displaced = 270 × 1.60 = 432 gm.
   ∴ Weight of object in carbon tetrachloride = 2700 — 432 (Archimedes' Principle)
   = 2268 gm.
   Archimedes' Principle is used for the accurate determination of the specific gravity of solids and liquids (Chap. 5, Exp. 7-9).

I : 12 PRINCIPLE OF FLOTATION

Archimedes' Principle applies to floating bodies as well as to those which are submerged in a fluid. When a body is floating in a liquid it appears to lose all its weight, as can be shown by lowering into water a block of wood, suspended by a thread from the hook of a spring balance (Fig. 4:3). As the wood settles more deeply into the water the reading of the spring balance decreases until, when the wood is floating, it records zero weight. The entire weight of the wood is now being supported by the upthrust of the water, this being equal to the weight of water displaced. We thus have, for floating bodies, the **Principle of Flotation**, which states that the weight of a floating object is equal to the weight of the fluid (liquid or gas) it displaces when floating. A fairly heavy object will of course sink lower in the liquid in which it is floating than will a lighter object. In either case the submerged portion has displaced an amount of liquid equal to the weight of the floating object.

This statement is embraced in Archimedes' Principle, i.e., a body which floats has lost its whole weight. (Remember that this loss is an apparent one, not real. The pull of the earth on the floating body is still the same.) Experimental proof for this Principle is supplied in Chap. 5, Exp. 10.

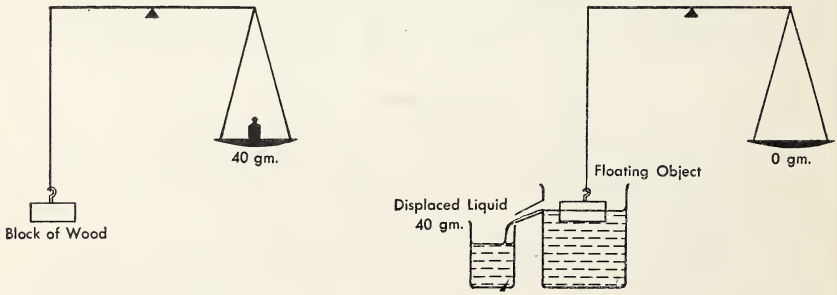


Fig. 4:3 Principle of Flotation.

Examples

1. An object loaded onto a flat barge 18 feet long and 10 feet wide, causes it to settle 2 inches deeper into the water. Calculate the weight of the object.
   Volume of water displaced $= 18 \times 10 \times 2/12 = 30$ cu. ft.
   Weight of water displaced $= 30 \times 62.5 = 1875$ lb.
   (Density of water $= 62.5$ lb./cu. ft.)
   $\therefore$ weight of object $= 1875$ lb. (Principle of Flotation)
2. A plastic tray 25 cm. long, 15 cm. wide is floating on water. A lead weight whose mass is 300 gm. when placed in it causes it to sink deeper into the water.
   Calculate the depth to which it sinks.
   Let the depth to which it sinks be x cm.
   $\therefore$ Volume of water displaced $= 25 \times 15 \times x = 375\,x$ c.c.
   $\because$ Density of water $= 1$ gm./c.c.
   $\therefore$ Weight of water displaced $= 375\,x$ gm.
   $\because$ Weight of water displaced = weight of floating object. (Principle of Flotation)
   $\therefore$ Weight of water displaced $= 300$ gm.

$$375\,x = 300$$

$$x = \frac{300}{375} = .8$$

   $\therefore$ Depth to which the tray sinks is .8 cm.

I : 13 HYDROMETERS AND THEIR USES

(a) Structure

The Principle of Flotation finds application in the hydrometer, which is a convenient instrument for the rapid determination of the specific gravity of liquids (Chap. 5, Exp. 11, 12). A common type of hydrometer consists of a cylindrical stem, graduated or containing a paper scale, an expansion of the stem called the float, and a bulb weighted with mercury or lead shot, the ballast, to make it float upright (Fig. 4:4). The float increases the buoyancy of the hydrometer.

The liquid whose specific gravity is to be determined is poured into a tall jar. The hydrometer is gently lowered into the liquid until it floats freely. The specific gravity of the liquid is indicated by the number on the scale which is even with the surface of the liquid. Since the hydrometer sinks until it has displaced its own weight of the liquid, the lighter the liquid, the deeper the hydrometer will sink in it. Therefore, the largest specific gravity readings are

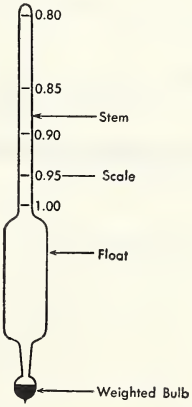


Fig. 4:4 Structure of a Hydrometer.

at the bottom of the scale, and the smallest at the top. Hydrometers used for liquids lighter than water have a large float, and scale gradations starting with a specific gravity of 1.000 at the bottom. Those used for liquids heavier than water have a small float, and scale gradations starting with 1.000 at the top. A universal hydrometer has 1.000 in the centre so that it may be used for

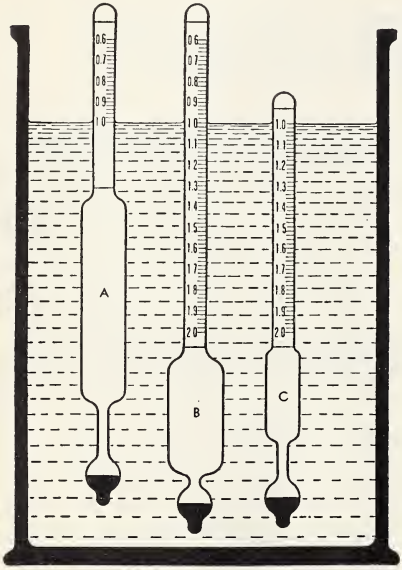


Fig. 4:5 Hydrometers of Different Types.
A—for liquids less dense than water
B—universal
C—for liquids denser than water

both kinds of liquids (Fig. 4:5). Since few scale readings can be accommodated above and below, such an instrument has a narrow range of usefulness.

(b) Principle

The principle of the hydrometer can best be illustrated by means of the simple hydrometer (Fig. 4:6). This consists of a straight wooden rod about 25 cm. long and having a cross-sectional area of 1 sq. cm. It is weighted at one end with a plug of lead. On one face is marked

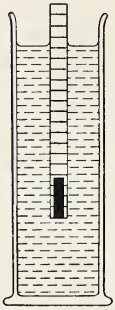


Fig. 4:6 Principle of the Hydrometer.

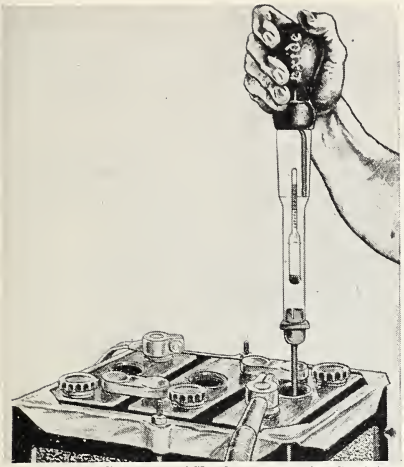
a centimetre scale, and the rod has been rendered impervious to water by dipping in hot paraffin.

Float the rod in water and note the depth to which it sinks, for example, 15 cm. Hence it displaces 15 c.c. or 15 gm. of water, and thus the weight of the hydrometer is 15 gm.

Now float it in some liquid whose specific gravity is to be determined, and note the level to which it sinks, for example, 20 cm. Hence the volume of the liquid displaced is 20 c.c. and the mass of an equal volume of water is 20 gm. But note, the weight of liquid displaced is equal to the weight of the hydrometer, namely, 15 gm. That is, the mass of liquid displaced is 15 gm. and the mass of an equal volume of water is 20 gm. It follows, therefore, that the specific gravity of the liquid is 15/20 or .75, and its density is .75 gm. per c.c.

(c) Uses

Hydrometers, of course, are widely used beyond the walls of the physics laboratory for testing liquids. Industries using or preparing syrups, salt solutions, petroleum products, acids and heavy



Courtesy of Exide Automotive Division

Fig. 4:7 Storage Battery Hydrometer.

chemicals make extensive use of them. The storage-battery hydrometer (Fig. 4:7) is used for testing the specific gravity of the acid in a battery, and hence for estimating the degree to which the battery is charged. Antifreeze hydrometers are used to measure the specific gravity of antifreeze and thereby indicate how low a temperature it can stand without freezing. Similarly lactometers are used in the testing of milk for checking possible dilution, and alcoholometers are used for estimating the strength of beers and wines.

I : 14 OTHER APPLICATIONS OF BUOYANCY

Archimedes' Principle and the Principle of Flotation apply wherever fluids are displaced, and the following ex-

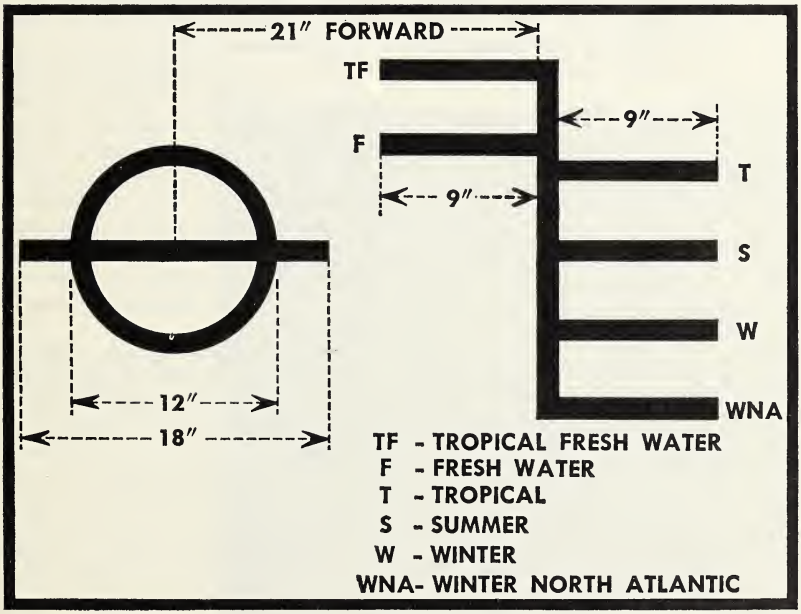


Fig. 4:8 The Plimsoll Mark.

The Plimsoll mark is painted amidships on the ship's hull to indicate safe-loading levels under different conditions (scale: 1¼ in. = 1 ft.).

amples are a few which show how important these principles are:

(a) Ships

Even when its hull is made of iron (density 7.9 gm. per c.c.) a ship floats on water because, being hollow, its average density is less than that of water. When it is launched it will sink to the level at which the weight of the water it displaces is equal to the entire weight of the ship, and hence the meaning of the term "displacement". A ship like the *Queen Elizabeth*, of 85,000 tons displacement, displaces 85,000 tons of sea-water when afloat. To ensure that it does not sink more deeply than is safe in the water, each ship has a safe-loading line, known as the Plimsoll line (Fig. 4:8) painted on its hull. Actually there are several such lines, to allow for regional and seasonal variations. These marks indicate the depth to which the ship may be safely loaded under the different conditions.

(b) Submarines

A submarine is a vessel with a cylindrically shaped enclosed hull fitted with ballast tanks at bow and stern and with smaller tanks on either side amidships. In order to submerge, the submarine allows water to enter these tanks until the total weight of the boat and ballast is nearly as great as that of the water it can displace. The submarine is now in "diving trim" and, by a proper use of horizontal or diving rudders, it can submerge completely and maintain its depth below the surface. In order to resurface, it forces the water out of its ballast tanks with compressed air. This action reduces its total weight until, when the weight is less than the upthrust, the ship rises.

(c) Floating Docks

When the hull of a great liner is to be serviced and reconditioned, a floating dock is used to lift it out of the water. This dock consists, essentially, of a large flat tank divided into several compartments which can be filled with water to

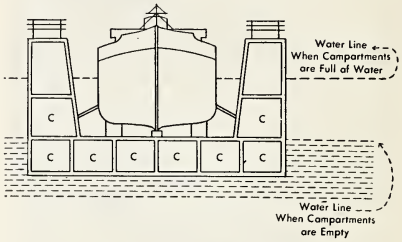


Fig. 4:9 Floating Dry-dock.

sink the dock to a sufficient depth for the ship to be drawn into it by tugs. The water is then blown out of the tanks by compressed air, and the dock rises, lifting the ship with it (Fig. 4:9).

(d) Balloons

When we apply Archimedes' Principle to air, we see that a body in air will experience a force of buoyancy equal to the weight of air it displaces. A balloon will rise if the weight of the air displaced is greater than the weight of the balloon envelope and its attachments. It will continue to rise until it reaches a level of more rarified air where the weight of the air displaced is equal to that of the balloon.

The first balloons, built in 1783, employed hot air for upthrust, having open bottoms with burning braziers slung underneath them, but by August of the same year the French scientist Charles had sent up the first balloon to be filled with the newly discovered gas, hydrogen. Two years later a trip was made from France to England in such a balloon, motive power being provided by oars.

Modern balloons are made of a gas-tight silk fabric fitted with valves. Increased height is obtained by releasing water or sand ballast, while the descent

is brought about by slowly releasing the gas from the envelope. Then, since atmospheric pressure decreases with height, the gas inside the balloon expands as it rises (in accordance with Boyle's law) and thus there is danger that the balloon will burst at great heights. For this reason, in balloon ascents to high altitudes, the envelope is not filled to capacity at ground level.

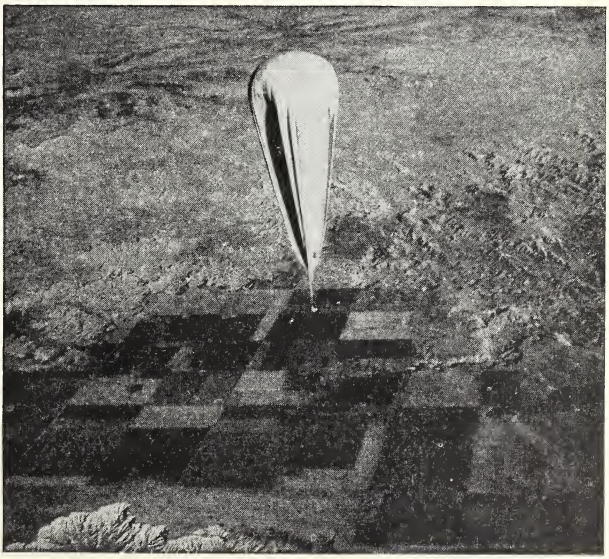
The greatest height reached by a manned balloon, 72,395 feet (over 13½ miles) was made by Stevens and Anderson, two United States Army officers, at Rapid City, South Dakota, in 1935. Their trip was made in a tightly-sealed hollow metal sphere attached to a huge helium-filled balloon.

(e) Weather or Sounding Balloons

The main use of hydrogen balloons today is to collect information about the upper atmosphere for meteorological purposes. These sounding balloons, as they are called, expand as they rise, until they spring a leak or burst, when the meteorological instruments which they carry are parachuted to earth. Temperature, pressure and humidity reports at various altitudes are automatically sent to weather stations by radio transmitters. Analysis of the readings have shown that sounding balloons have reached heights of 25 miles or more.

(f) Airships

An airship is a balloon built on a light rigid framework, propelled by air-screws and steered by rudders. The design of this type of craft developed rapidly in the early decades of this century. Although long flights were successfully made in these ships, a series of disasters resulting from the ease with which they caught fire, has caused their further development to be abandoned.



A Modern Sounding Balloon.

Wheeler Newspaper Syndicate

I : 15 QUESTIONS

A

1. (a) State Archimedes' Principle.
(b) In air a piece of iron whose volume is 100 c.c. has a mass of 890 gm. When this is immersed in water, calculate:
(i) the buoyant force of the water on it.
(ii) the weight of the iron in water.

2. Describe briefly how Archimedes' Principle is used to determine the specific gravity of (a) a solid denser than water (b) a liquid.

3. (a) State the Principle of Flotation.
(b) Show that it is a modification of Archimedes' Principle.
(c) When a piece of wood is floated in water in a graduated cylinder the level rises from 15.7 ml. to 18.3 ml.
(i) Calculate the mass of the wood.
(ii) If its specific gravity is 0.60, what is its volume?

4. Explain how Archimedes could have determined whether King Hiero's crown was pure gold or a mixture of gold and silver.

5. Explain how Archimedes' Principle or the Principle of Flotation applies to each of the following statements:
(a) In landing a fish, you find that it seems to weigh more when it is pulled out of the water than it does beneath the water surface.
(b) As a ship in harbour is being unloaded, it slowly rises higher in the water.
(c) In order to make a submarine submerge, large tanks aboard it are filled with water.
(d) The same ship with the same cargo will ride higher on the Atlantic Ocean than on the Great Lakes.
(e) Plimsoll lines are used on ships.

6. (a) What is the purpose of a hydrometer?
(b) Why are the smaller numbers of the hydrometer scale near the top?
(c) Compare the size of float required for hydrometers used for denser and less dense liquids. Explain the difference.

7. State three methods used for finding the specific gravity of a liquid. Which of the three do you think is the most accurate? Why?

B

1. (a) If 15 c.c. of material weigh 45 gm. in air, find the weight when immersed in water.
(b) If 3 cu. ft. of a substance weigh 350 lb. in air, find the weight when immersed in water.

2. (a) Iron has a density of 7.8 gm. per c.c. Find the weight of 10 c.c. of it when immersed in water.
(b) A substance has a density of 187.5 lb. per cu. ft. Find the weight when 5 cu. ft. of it are immersed in water.

3. (a) If an object weighs 140 gm. in air and 115 gm. in water, what is the volume of the water displaced?
(b) If an object weighs 140 lb. in air and 115 lb. in water, what is the volume of the water displaced?

4. A piece of silver weighs 65.1 gm. in air and 58.9 gm. in water. Find its specific gravity.

5. A piece of metal weighs 500 gm. in air and 430 gm. in water. (i) What is its specific gravity? (ii) What is its volume?

6. A 15 lb. weight weighs only 9 lb. in water. (i) Find its specific gravity. (ii) Find its volume. (iii) Find its density.

7. A piece of metal weighing 120.4 gm. has a volume of 14.5 c.c. (i) What will it weigh in water? (ii) Find also the density of the metal.

8. An object weighs 42.2 gm. in air, 29.4 gm. in water and 25.6 gm. in a liquid.

Calculate the specific gravity of the liquid.

9. A metal weighs 56.3 gm. in air, 45.8 gm. when immersed in water and 48.6 gm. when immersed in a liquid. Calculate the specific gravity of (i) the metal (ii) the liquid.

10. A piece of metal weighs 138.8 gm. in air, 123.2 gm. in water and 125.7 gm. in a liquid. Find the specific gravity of the metal and of the liquid.

11. An object weighs 42.2 gm. in air and 29.4 gm. in water. How much will it weigh in a liquid of density 0.80 gm. per c.c.?

12. Was King Hiero's crown made of pure gold if in air it weighed 1500 gm., and when immersed in water it weighed 1400 gm.?

13. A rectangular block of soap 8 cm. long and 6 cm. wide floats in water with 2.5 cm. of its thickness submerged. Calculate the mass of the soap.

14. A cube of wood, side 50 cm., floats in water with its base horizontal and 6 cm. of its height above the surface. Find its density.

15. A wooden raft 5 ft. long and 4 ft. wide floats in water. When a person steps on the raft it sinks 1.5 inches deeper into the water. Calculate the person's weight.

16. A cork of volume 60 c.c. and density 0.24 gm. per c.c. floats in a liquid of density 0.85 gm. per c.c. Find the least weight required to sink it.

17. What volume of lead of density 11.2 gm. per c.c. will be required to sink a piece of wood in water, the weight of the wood being 425 gm. and its volume 556 c.c.?

18. A block of wood of volume 100 c.c. floats in a liquid of specific gravity 1.2 with 75 c.c. immersed. Calculate the density of the wood.

19. A wooden hydrometer sinks in water to a depth of 18 cm. and in a liquid to a depth of 14 cm. What is the specific gravity of the liquid?

20. A hydrometer sinks in water to a depth of 15 cm. How far would it sink in a liquid whose specific gravity is 0.80?

21. A hydrometer sinks to a depth of 12 cm. in a liquid whose specific gravity is 1.7. To what depth would it sink in water?

22. A piece of wood whose volume is 150 c.c. floats with $\frac{2}{3}$ of its volume submerged in water. Find its mass.

23. A piece of wood whose mass is 75.0 gm. floats in water with $\frac{3}{5}$ of its volume above the surface. Find its volume.

24. A piece of cork of density 0.25 gm. per c.c. floats in a liquid of density 1.2 gm. per c.c. What proportion of the volume of the cork will be immersed?

25. An object floats in water with half its volume submerged. How much will be submerged when it floats in a liquid of specific gravity 1.5?

26. To what depth will a block of wood 20 cm. high and of density 0.63 gm. per c.c. sink in a liquid of density 0.90 gm. per c.c.?

CHAPTER 5 EXPERIMENTS ON MECHANICS

INTRODUCTION

Before proceeding with the following experiments the student should review the following techniques used in measurement.

A. — Use of the ruler

1. Avoid using the ends of the ruler.
2. Place your eye directly above the point where the reading is to be taken to avoid the error due to parallax.

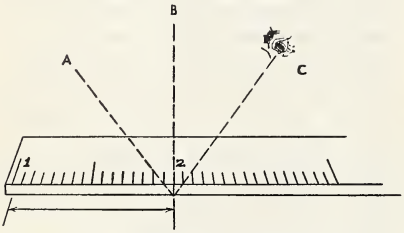


Fig. 5:1 Measuring Length with a Ruler—How to Avoid the Error Due to Parallax.

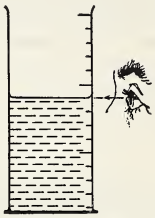


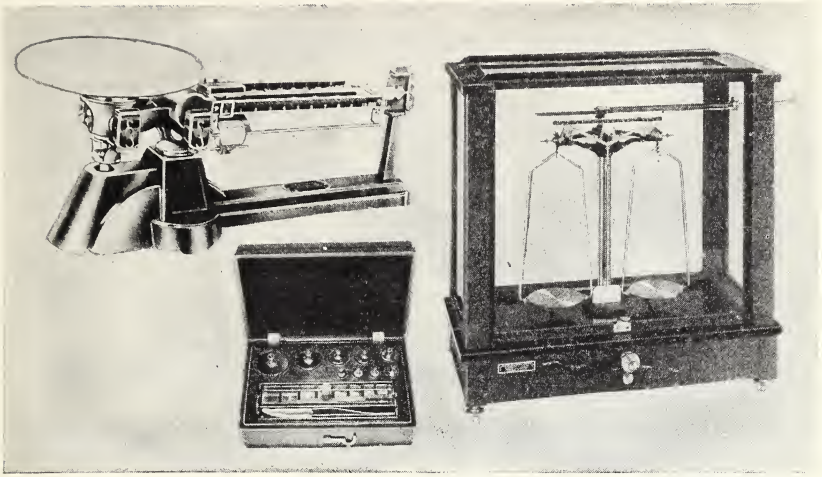
Fig. 5:2 Measuring Volume with a Graduated Cylinder.

B. — Use of the graduated cylinder

Place your eye directly opposite the centre of the meniscus curve. Take the reading at this level.

C. — Use of the balance

1. Clean and level the balance.
2. Support the beam of the balance on the knife-edge as demonstrated by the instructor.
3. Adjust for zero reading with all weights removed. Note that in all readings the pointer should swing an equal number of divisions on either side of the zero mark on the scale. Do not wait for the pointer to come to rest.
4. Place object to be weighed on the centre of the left pan of the balance.
5. Commencing with a weight that is definitely too heavy on the right-



A B

Fisher Scientific Co.
Canadian Laboratory Supplies Ltd.

Fig. 5:3 The Balances A—Triple-beam balance.
B—Equal-arm balance and box of weights.

hand pan of the equal-arm balance (or on the arm of the triple-beam balance), systematically reduce the weight until balance is attained.

6. Total the weights used.
7. Disengage the knife-edge and return all weights to their box or to their zero position.

EXPERIMENT 1

To determine the density of a regular solid. (Ref. Sec. I:5)

Apparatus

Rectangular solid, ruler (graduated in mm.), balance.

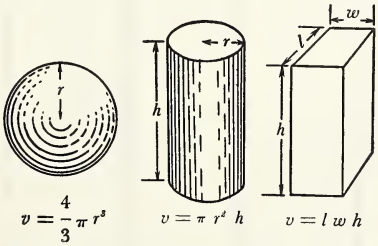


Fig. 5:4

Method

1. Carefully measure to the nearest millimetre the length, width and

thickness of a rectangular solid.* Record your measurements, and calculate the volume of the object in cubic centimetres.

2. Determine the mass of the object and record it in grams.

Observations	Length	=	cm.
	Width	=	cm.
	Thickness	=	cm.
	Mass	=	gm.

Calculations

1. What is the volume of the object?
2. Determine the mass of one cubic centimetre.
3. What is the average of the results obtained by the class?

Conclusion

What is the density of this material?

Questions

1. What is the correct value for the density of this material? (Table p. 21).
2. Express the difference between the class average and the true value as a percentage of the true value. This is a measure of the experimental error.
3. Suggest sources of experimental error.

* *Note* The density of other regular solids, such as a cylinder (Volume $= \pi r^2 h$), or a sphere (Volume $= \frac{4}{3}\pi r^3$) may be determined in a similar way (Fig. 5:4).

EXPERIMENT 2

To determine the density of an irregular solid (rubber stopper). (REF. SEC. I:5)

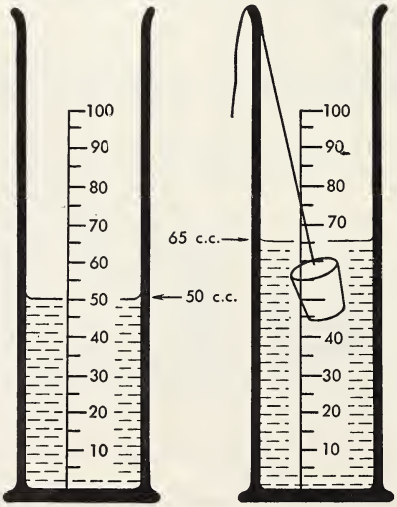


Fig. 5:5

Apparatus

Rubber stopper, thread, graduated cylinder, water, balance.

Method

1. Determine the mass of the object and record it in grams.
2. Half fill a graduated cylinder with water. Note and record the volume of the water. Tie a thread to the object and carefully lower it into the water until it is completely immersed. Note and record the final volume of the water and object. Determine the volume of the object and record it in cubic centimetres.

Observations

Mass of object	=	gm.
Initial volume of water	=	c.c.
Final volume of water and object	=	c.c.
∴ Volume of object	=	c.c.

Conclusion

What is the density of this material?

Question

Why should the object be weighed before its volume is determined?

EXPERIMENT 3

To determine the density of a liquid by measurement. (Ref. Sec. I:5)

Apparatus

Beaker, graduated cylinder, balance, liquid (water, alcohol, etc.).

Method

1. Determine the mass of a clean dry beaker.
2. Add about 50 c.c. of the liquid to the beaker, weigh, and hence determine the mass of the liquid used.
3. Pour the liquid into a graduated cylinder and determine its volume.

Observations

Mass of beaker	=	gm.
Mass of beaker plus liquid	=	gm.
∴ Mass of liquid	=	gm.
Volume of liquid	=	c.c.

Calculations

Determine the mass of one cubic centimetre.
What is the average of the results obtained by the class?

Conclusion

What is the density of this liquid?

Questions

1. What is the correct value for the density of this liquid? (Table p. 21)
2. Calculate the percentage error.
3. Suggest sources of experimental error.
4. If the balance at your disposal is suitable, a graduated cylinder, instead of a beaker, could be used in steps 1 and 2 in the above experiment. Why should this tend to reduce the experimental error?

EXPERIMENT 4

To determine the specific gravity of a liquid by means of the specific gravity bottle. (REF. SEC. I:7)

Apparatus

Specific-gravity bottle, water, balance, liquid (carbon tetrachloride, alcohol, etc.)

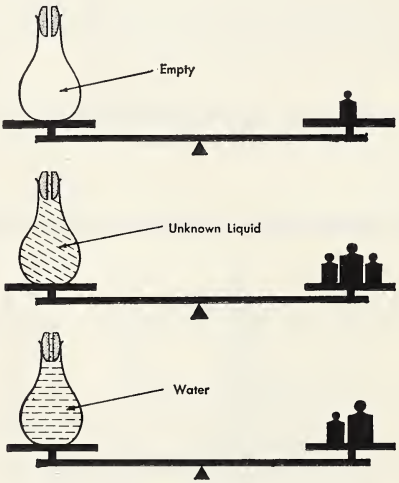


Fig. 5:6

Method

1. Carefully clean and dry the bottle. Determine its mass.
2. Fill completely with the liquid whose specific gravity is to be determined. Insert the stopper, wipe off any excess liquid that exudes through the opening. Determine the mass of the bottle plus the liquid.
3. Pour out the liquid. Rinse out the bottle with water. Fill the bottle completely with water. Determine the mass of the bottle plus the water.

Observations

Mass of specific-gravity bottle empty	=	gm.
Mass of specific-gravity bottle full of liquid	=	gm.
∴ Mass of liquid	=	gm.
Mass of specific-gravity bottle full of water	=	gm.
∴ Mass of water	=	gm.

Conclusion

What is the specific gravity of the liquid?

Questions

1. Define specific gravity.
2. Calculate the percentage error.
3. Suggest sources of experimental error.
4. What is the purpose of the hole through the centre of the stopper of the specific-gravity bottle?

EXPERIMENT 5

To demonstrate Archimedes' Principle. (Ref. Sec. I:11)

Apparatus

Balance, bucket and cylinder apparatus, beaker, water.

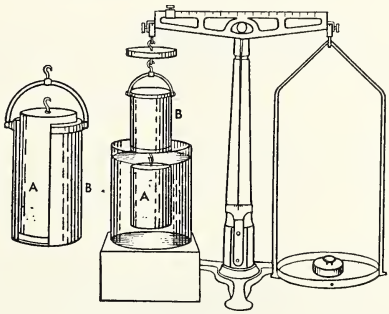


Fig. 5:7

Method

1. Hook the cylinder A on the bottom of the bucket B. Suspend them from the hook on the balance. Adjust the weights until the balance is in equilibrium.
2. Completely immerse the cylinder in a beaker of water. Be sure that the cylinder does not touch the bottom or sides of the beaker. Note the effect on the equilibrium.
3. Carefully add water to the bucket until it is completely full. Again note the effect on the equilibrium.

Observations

1. What was observed when the cylinder was completely immersed in the water?
2. What was observed when the bucket was filled with water?

Conclusions

1. Why was the equilibrium disturbed in step 2?
2. Why was the equilibrium restored in step 3?
3. State Archimedes' Principle.

Questions

1. Why do objects apparently weigh less when immersed in a liquid?
2. What would be the effect of immersing the object in a denser liquid?

EXPERIMENT 6

Alternative method to demonstrate Archimedes' Principle.
(REF. SEC. I:11)

Apparatus

Balance, object (glass stopper), beaker, overflow can, catch bucket, water, several other liquids (alcohol, carbon tetrachloride, brine, etc.)

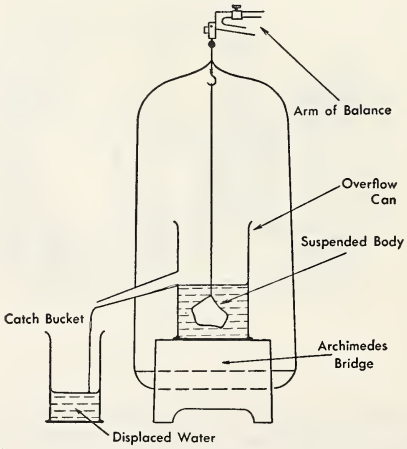


Fig. 5:8

Method

1. Suspend the object from the hook on the balance. Determine its mass in air.

2. Completely immerse the object in a beaker of water. Be sure that it does not touch the beaker. Weigh the object while immersed in water.
3. Weigh a dry empty catch bucket.
4. Completely fill an overflow can with water. Let any excess water flow freely from the spout and discard it. Do not disturb the overflow can. Place the catch bucket under the spout. Carefully lower the object into the water and catch all of the overflow in the bucket. Weigh the catch bucket and overflow water.
5. Repeat the above using other liquids and fill in the table below.

Observations

Liquid Used	Water	Alcohol	Carbon Tetrachloride
Weight of object in air			
Weight of object in liquid			
∴ Apparent loss of weight in liquid			
Weight of empty catch bucket			
Weight of bucket plus displaced liquid			
∴ Weight of displaced liquid			

Conclusions

1. How does the apparent loss of weight compare with the weight of liquid displaced?
2. State Archimedes' Principle.

Questions

1. Why is a glass stopper an ideal solid to use in the above experiment?
2. What type of solid must be avoided?

EXPERIMENT 7

To determine the specific gravity of a solid which is more dense than water using Archimedes' Principle. (Ref. Sec. I:11)

Apparatus

Balance, beaker, water, thread, several solid objects more dense than water.

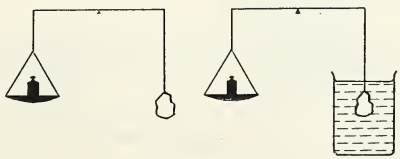


Fig. 5:9

Method

1. Suspend a solid object by a thread from the hook on the balance. Determine its weight in air.
2. Completely immerse the object in a beaker of water. Be sure that it does not touch the beaker. Determine the weight of the object when immersed in water.
3. Repeat the above weighings for other objects supplied and fill in the table below.

Observations

OBJECT	WEIGHT IN AIR	WEIGHT IN WATER	APPARENT LOSS IN WEIGHT
1.			
2.			
3.			

Calculations

Weight of object in air = gm.
Apparent loss in weight = gm.
∴ Weight of water displaced = gm. (Archimedes' Principle)

$$\because \text{Specific gravity} = \frac{\text{Weight of object in air}}{\text{Weight of equal volume of water}}$$

∴ Specific gravity =

Conclusion

What is the specific gravity of the object?

Questions

1. Calculate the percentage error.
2. Suggest sources of experimental error.
3. Explain how the weight of an equal volume of water was determined.
4. State the density of the above objects in the metric system of units.
5. Discuss advantages and disadvantages of this method for finding density compared with the method used formerly (Exp. 2).

EXPERIMENT 8

To determine the specific gravity of a liquid using Archimedes' Principle. (REF. SEC. I:11)

Apparatus

Balance, glass stopper, thread, several beakers, water, liquid (alcohol, carbon tetrachloride, etc.).

Method

1. Suspend the object by a thread from the hook on the balance. Determine its weight in air.

2. Immerse the object in a beaker of water, being careful not to let it touch the beaker. Determine the weight of the object when immersed in water.
3. Rinse the object in a reserve supply of the liquid whose specific gravity is to be determined. Immerse the object in a beaker of this liquid and again weigh.
4. Repeat for other liquids supplied.

Observations

Liquid Used	Weight of Object in Air	Weight of Object in Water	Weight of Object in Liquid
Alcohol			
Carbon tetrachloride			

Calculations

Mass of water displaced = gm.
Mass of liquid displaced = gm.
Calculate the specific gravity of this liquid.

Conclusion

What is the specific gravity of the liquid used?

Questions

1. Calculate the percentage error.
2. Suggest sources of error.
3. Explain how the mass of water displaced or of liquid displaced was obtained in the above experiment.
4. Why was it correct to say that the volumes of water displaced and of liquid displaced were equal?

EXPERIMENT 9

To demonstrate the Principle of Flotation. (Ref. Sec. I:12)

Apparatus

Balance, paraffined wooden block, overflow can and catch bucket, water, other liquids.

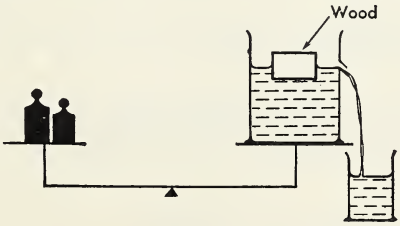


Fig. 5:10

Method

1. Place the overflow can on the pan of the balance. Fill the overflow can to the spout with water (Exp. 6). Balance it.
2. Without adjusting the weights, and after placing the catch bucket under the spout of the overflow can, carefully lower the wooden block into the water. Let it float freely being careful not to let it touch the sides of the can. Note all changes that occur until the water ceases to flow.
3. Repeat this experiment using the other liquids provided.

Observations

Describe the changes in equilibrium that occurred.

Conclusions

1. How does the mass of the floating block compare with the mass of liquid it displaces?
2. State the Principle of Flotation.

Questions

1. Why was the block of wood used in the above experiment coated with a thin film of paraffin?
2. Why does a steel ship float?

EXPERIMENT 10

To show the principle of the hydrometer. (REF. SEC. I:13)

Apparatus

Simple hydrometer (Fig. 4:6), two tall cylindrical vessels, water, other liquids.

Method

1. Float the hydrometer in a cylinder of water, being careful that it does not touch the sides. Note the depth to which it sinks in the water. Calculate the mass of the hydrometer.
2. Rinse the hydrometer in a reserve supply of the liquid to be used. Then float the hydrometer in a cylinder of the liquid, again being careful not to let it touch the sides. Record the depth to which it sinks in the liquid.
3. Repeat part 2 for other liquids.

Observations

1. Depth to which hydrometer sinks in water =
2. Depth to which hydrometer sinks in the liquid =

Calculations

Calculate the specific gravity of the liquid.

Conclusions

1. What is the specific gravity of the liquid?
2. On what principle does the use of the hydrometer depend?

Questions

1. How do you find the mass of the hydrometer?
2. How do you find the mass of the liquid displaced?
3. How is the depth that the hydrometer sinks related to the specific gravity of the liquid?
4. What is the use of the hydrometer?

EXPERIMENT 11

To determine the specific gravity of a liquid using a hydrometer. (Ref. Sec. I:13)

Apparatus

Several tall cylindrical vessels, several liquids (brine, alcohol, etc.), three hydrometers (one for heavy liquids, one for light liquids, one universal).

Method

1. Float an appropriate hydrometer in a cylinder containing the liquid whose specific gravity is to be determined. Be careful not to let it touch the sides of the vessel. Determine the specific gravity by reading the hydrometer scale at the liquid surface level.
2. Repeat for other liquids.

Note This hydrometer method can be used to check the specific gravities of liquids obtained in previous experiments.

Observations

Liquid	Specific Gravity

Conclusion

State the specific gravity of each liquid used.

Questions

1. Describe the construction of a hydrometer.
2. Why is the lower end of the hydrometer weighted (with mercury or lead shot)?
3. Is the flotation bulb on a hydrometer for low-density liquids larger or smaller than the bulb on a hydrometer for high-density liquids? Explain.
4. Why is the hydrometer scale graduated with the smallest readings at the top and the largest at the bottom? Explain.

UNIT II

SOUND

Star Newspaper Service

Describe the different ways in which the sound of this depth charge would be heard below and above the water, and why.

CHAPTER 6 PRODUCTION AND TRANSMISSION OF SOUND

II:1 INTRODUCTION

From earliest childhood our ears grow accustomed to sounds about us: first the sound of our mother's voice, then the sounds of home, of nature, and the busy world. Our consideration of their nature rarely goes further than calling the sounds we dislike noises, and some of the more pleasant ones music. These, however, are often subjective definitions, as can be seen from the fact that a "hot-rodder" may drive for miles in his unmuffled car and think the sound it is making is "music", while he will hurriedly turn off the radio because of the "noise" Beethoven is making.

Man, in fact, has been interested in inventing devices for making music and noises for much longer than in investigating the nature of sound. References to musical instruments in the Old Testament date back to 4000 B.C. Remember the story of Joshua and the walls of Jericho. Yet, although Aristotle and the early philosophers knew something of the physical nature of sound, it is only in the last four or five hundred years that a fuller understanding of it has been gained.

The word sound has been used frequently already, but no effort has so far been made to define it. One definition calls it the sensation that results when the auditory nerve is stimulated, while another refers to the physical causes of this sensation, in terms of the three necessary agencies for any sound: a source, a medium and a receiver. It is this second definition of sound which will be our concern in this unit.

II:2 THE ORIGIN OF SOUND

When we ring a bell, bow a string, or strike a tuning-fork, and bring each into contact with a light object such as a pith ball, the object moves away as if being struck regularly (Fig. 6:1). Some demonstrators may prefer to touch the sounding body to some water and note

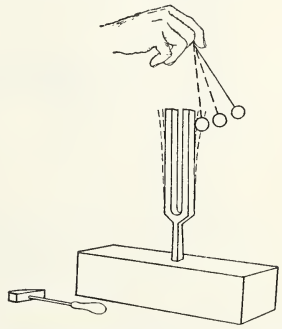


Fig. 6:1 Sounding Bodies Vibrate.

the splash and waves set up. This is ample proof that the sounding body is vibrating, i.e., moving to and fro. It may be concluded that sound always

originates in a rapidly vibrating body.

Only sufficiently rapid vibrations cause sound, but some vibrations, whether or not they emit sound, have other effects, such as the destruction of buildings, bridges, or parts of moving machinery. To take one instance, the vibration set up by a body of troops marching would be sufficient to destroy some bridges and so troops marching across them have to break step. Obviously the study of vibratory motion is one of great importance.

II:3 A STUDY OF VIBRATORY MOTION

(a) The Pendulum and Transverse Vibrations

A simple device for demonstrating vibrations is the pendulum (Chap. 10, Exp. 1). This consists of a weight, called the bob, attached to the free end of a vertical cord, the other end of which is securely attached to a support (Fig. 6:2). When the weight is drawn aside and allowed to swing, it will be seen that the pendulum swings back and forth in a regular manner and that it moves about the same distance on either side of the point of rest or mean position.

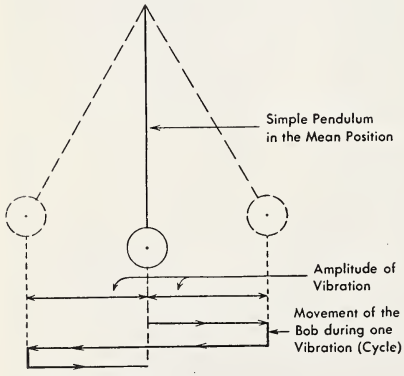


Fig. 6:2 Transverse Vibrations.

The advantage of using a pendulum to study vibrations is that the action is slow enough to be noted in every detail. For example, if we draw the bob aside and let it move to and fro once the pendulum will have performed one **vibration** or **cycle**. Most objects would vibrate too fast to allow this to be seen. The horizontal displacement that the bob undergoes on either side of its natural rest position is the **amplitude** of the vibration. This is the destructive element of vibratory motion that affects rigid and brittle components of buildings, bridges, machinery and the like. Moreover, we shall see later (Sec. II:11) that it affects the loudness of sound. To the movement of the pendulum, which is obviously at right angles to the mean position, is ascribed the term **transverse vibration.** Although there are other kinds of vibrations, you will recognize this kind in some of the objects used to demonstrate the origin of sound.

Counting the number of vibrations in a given time, say 30 seconds, enables us to determine two other important properties of vibrations. If we calculate the number of vibrations per second, we know the **frequency** of vibration. Differences in the frequencies of musical notes account for differences in pitch of the sounds (Sec. II:12). If we determine the time in seconds required for one vibration, we know the **period** of vibration. You will discover that all pendulums of the same length will have the same period. It is for this reason that the pendulum is frequently used in physics as a timing device. For that reason also, it is the primary component of large clocks. Were you to experiment with pendulums of different lengths, the period of a short one would be less than that of a long one. It is for this reason that you shorten the pendulum of a

clock which loses time and lengthen it for one that gains.

(b) Longitudinal Vibrations

A coil spring with a weight attached is supported vertically from a strong support as in Fig. 6:3. When it is vibrated

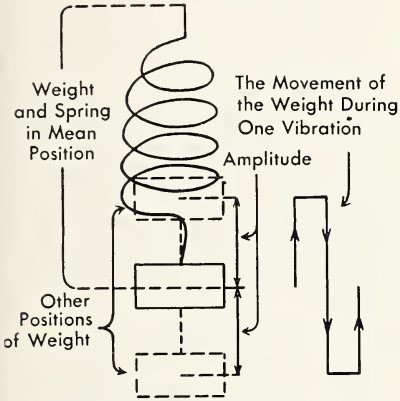


Fig. 6:3 Longitudinal Vibrations.

so that the weight moves vertically by alternately stretching and compressing the spring, longitudinal vibrations result. Fortunately the vibrations are slow

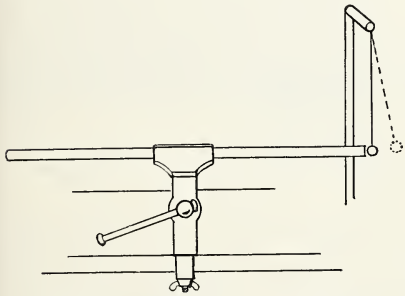


Fig. 6:4 Longitudinal Vibrations.

enough to enable us to observe all the details as in the pendulum (Chap. 10, Exp. 2).

Another demonstration may be arranged using a long metal rod, clamped at its centre, having a pith ball in contact with one end as in Fig. 6:4. When the half of the rod farthest from the pith ball is stroked with a chamois coated with resin, a shrill sound is emitted. Meanwhile the pith ball is displaced in the direction of the axis of the rod, thus showing longitudinal vibrations, although these are too rapid to be seen in detail. These examples indicate that **longitudinal vibrations** are characterized by motion back and forth along the length of the vibrating body.

II:4 MEDIA FOR THE TRANSMISSION OF SOUND

The need for a material medium for the transmission of sound is studied in

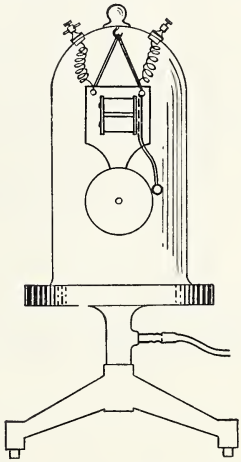


Fig. 6:5 Bell in Evacuated Bell-jar.

Chap. 10, Exp. 3. There it will be found that as the air is removed from the bell-jar in which there is a vibrating bell (Fig. 6:5), the sound gradually becomes fainter. The bell is heard again when air is reintroduced into the bell-jar. Since

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we could see the vibrating bell throughout the entire experiment but could not hear the sound when there was no air present, we conclude that sound, unlike light, cannot travel through a vacuum.

Sounds can also be conveyed through liquids and most solids. Thus the noise of the engines of a submarine can be picked up by underwater microphones, and the sound of vibrating telegraph wires can be clearly heard by an ear pressed against a telegraph post.

II:5 WAVE MOTION

(a) Transverse Waves

The disturbances set up by a vibrating body are propagated in the form of waves in the medium (Chap. 10, Exp. 4). A wave may be defined as a disturbance of any kind which travels without change of form and without the medium moving bodily with it. Simple examples of waves are to be seen when one end of a taut rope is jerked or when a stone is thrown into a pond and makes ripples on the surface. Waves produced in this way are known as **transverse waves**, since the disturbances in the medium are perpendicular or transverse to the direction of propagation of the waves. The ripples on water can be seen to travel outwards from the centre of the disturbance, but a cork floating on the surface will execute an up-and-down motion without moving away from or towards the point of origin of the waves. Again, if part of our rope were chalk-marked, this part would be seen as a white line perpendicular to the length of the rope when the latter was vibrated at one end to set up a train of waves along it. Electromagnetic waves (Sec. IV:38), which include light waves, are also transverse in character.

Fig. 6:6 shows the displacements of the particles of a medium transmitting a transverse wave. Particles at the crests (B, F, etc.) of the wave are undergoing a maximum displacement upwards, those at the bottom of the troughs (D, H, etc.) a maximum displacement downwards. Some terms used in wave motion follow:

Amplitude is the maximum displacement from the mean position (BB_1 or DD_1, etc.).

Phase. Particles at the same distance from their mean positions and which are moving in the same direction are said to be in the same phase. Thus particles P and Q are in the same phase, as also are particles B and F. On the other hand, particles B and D are completely out of phase.

Wave-Length (l) is the distance, usually expressed in centimetres or inches, between two consecutive particles in the same phase. Thus the distance BF between two adjacent crests, or the distance DH from one trough to the next, gives the wave-length of the disturbance. This

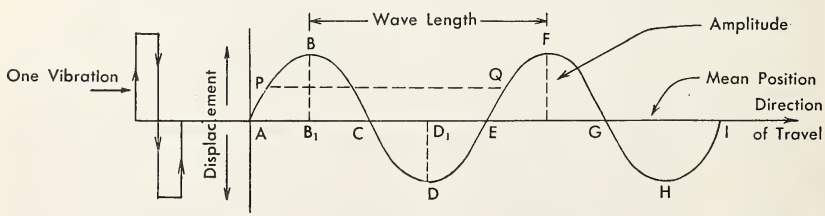


Fig. 6:6 Transverse Waves.

represents the distance that the motion has travelled during the execution of one complete vibration.

Period of a Vibration is the time of one complete vibration, or is the time taken by a particle in travelling from its mean position through the maximum displacement first in one direction and then in the other, finally returning to its mean position.

Frequency (n) is the number of vibrations in one second.

Wave-Train is a succession of waves caused by continuous vibration of the source.

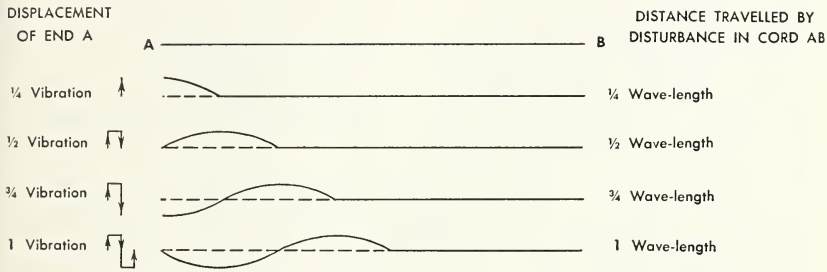


Fig. 6:7 Proving that V = nl.

Velocity (V) is the distance covered in a unit of time (a second). Since during one vibration the disturbance travels l cm. (one wave-length) (Fig. 6:7), then during n vibrations, the disturbance travels nl cm. (n wave-lengths). Now, if the frequency is n vibrations per second, the disturbance travels nl cm. in one second, i.e., the velocity is nl cm. per second. This gives us the **wave formula** found to be equally useful in all branches of physics.

Velocity = frequency × wave-length or V = nl.

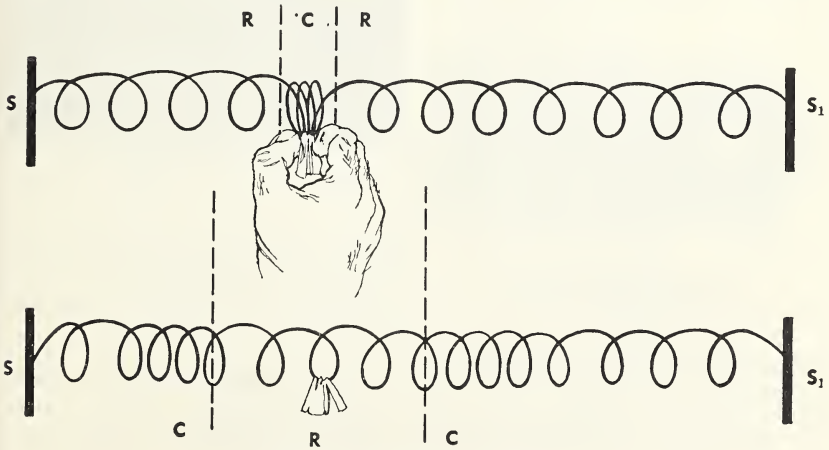


Fig. 6:8 Longitudinal Waves.

(b) Longitudinal Waves

Sound waves differ from those described above in that the particles of the medium are displaced from their mean positions backwards and forwards along the line of travel of the wave motion. Such waves are known as **longitudinal waves**, and may be illustrated by reference to Fig. 6:8. There we have a coil spring stretched between two supports (S, S_1). A piece of cloth is tied near its centre. When several coils of the spring are squeezed together a compression, or **condensation** (C) is formed. When the coils are released, their elasticity causes them to return to their normal position. The momentum so produced causes them to move past this position, thereby forming a stretched region or **rarefaction** (R).

A study of the jerking of the cloth to and fro along the length of the spring will give ample proof of what is happening. It will now be good practice to draw a longitudinal wave-train in a coil spring and label amplitude, particles in the same phase, and one wave-length. Longitudinal waves are always characterized by condensations and rarefactions.

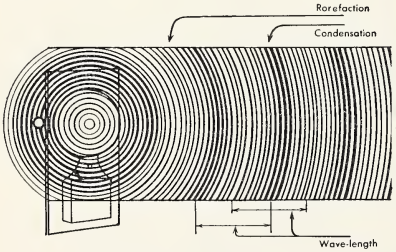


Fig. 6:9 Sound Waves.

Sound waves from a vibrating bell are depicted in Fig. 6:9. The transverse vibrations of the gong give rise to condensations and rarefactions alternately, i.e., longitudinal waves. As the sound is audible in all directions, each **wave-front**, i.e., the leading edge of each wave, must be spherical.

How the air responds to the vibrating bell may be illustrated with the aid of the apparatus shown in Fig. 6:10. The

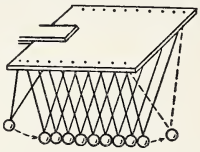
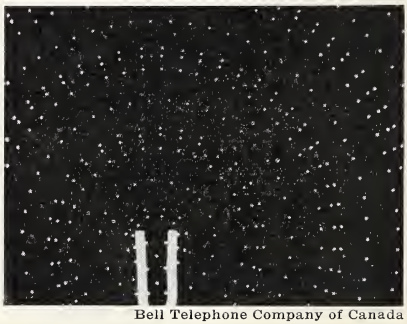


Fig. 6:10 Illustrating Longitudinal Wave Motion.

steel balls are suspended so that they just touch. When the first one is drawn aside and allowed to hit the ball next in line, none moves except the one at the opposite end. It flies out about as far as the first was drawn aside. Because steel is elastic, the impact is passed through



Bell Telephone Company of Canada

Sound Waves from a Vibrating Tuning-fork.

the line as a compression wave or condensation followed by an expansion or rarefaction. This is similar to the way in which sound waves are transmitted through air.

II:6 THE SUPERPOSITION OF WAVES

(a) Interference

Interesting effects are observed when

two waves are simultaneously propagated through the same medium. The resulting displacement at any point of the medium is the algebraic sum of the displacements produced by the two separate waves. When these are in the same direction the effects are thus reinforced, and when opposed they are diminished. In the special case where the two waves are of the same frequency and amplitude, as in Fig. 6:11 (a), each wave will assist the other at all points when the two waves are exactly in phase, the crests and troughs of the two waves exactly coinciding throughout the medium. If, however, they are completely out of phase as in Fig. 6:11(b) the two waves are in exact opposition at all points, the crests of one coinciding with the troughs of the other, and accordingly the resulting effect in the medium is nil. These phenomena are referred to under the general heading of **interference**. Special cases of particular interest to us in our study of sound will be presented in Sec. II:24.

(b) Standing Waves

A very important case of interference is seen when two trains of waves of the same frequency and amplitude travel in opposite directions through a medium, for example, original and reflected waves (Chap. 10, Exp. 5). To demonstrate this, attach a light flexible silk cord to one prong of a large tuning-fork. Pass the other end of the cord over a pulley and attach a weight to it. The tuning-fork should be activated by an electromagnet to give continuous vibration. In

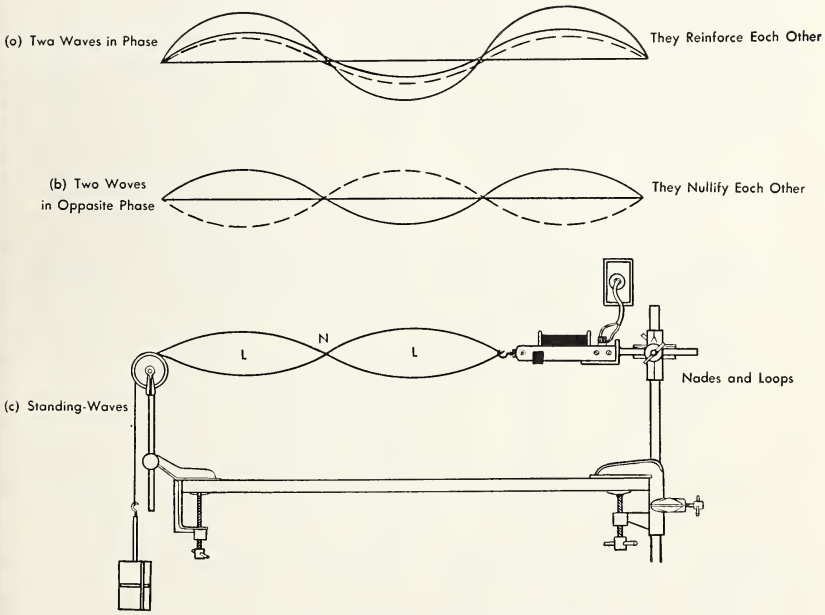


Fig. 6:11 Production of Standing Waves.

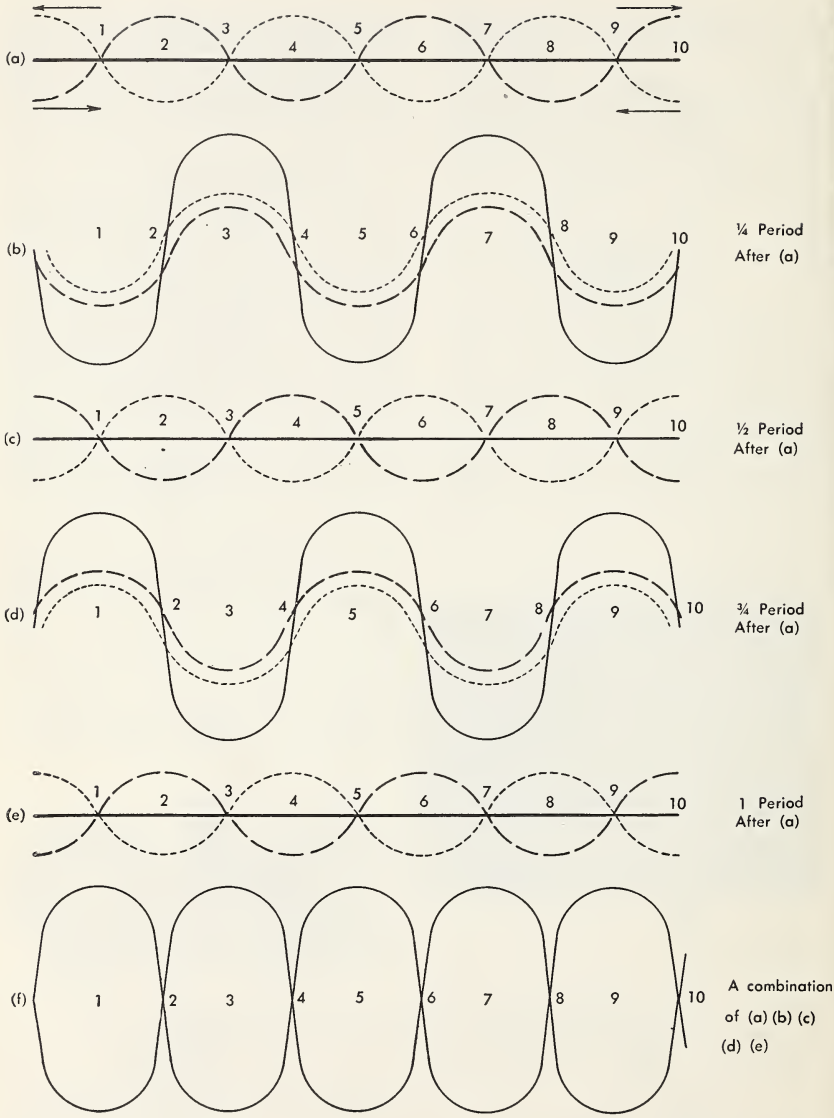


Fig. 6:12 Superposition of Waves.

place of the tuning-fork an electric bell with gong removed may be used, the cord being tied to the clapper, or a special vibrator as shown in Fig. 6:11 (c) may be employed. For reasons to be discussed later, the length of the cord is adjusted until it takes the form shown in the figure. The hazy oval regions where displacement of the cord is greatest are called **loops**. The points of quiet as well as the ends where reflection occurs are called **nodes**. It might be imagined that a loop would occur where the cord meets the vibrator but, in reality, the amplitude of the vibrator is so small compared to that of the cord that it must be considered to be a node. In any case some reflection occurs there.

The reason for adjusting the length of the cord is rather too difficult to be explained here. However, this much can be said, that the wave-length of the disturbance depends on the tension (caused by the weight) and the frequency of the source. Since each loop is half a wave-length and there must be a whole number of loops in the cord, the length must be adjusted to accommodate a whole number of loops.

An examination of Fig. 6:12 will help us to understand the phenomenon. The wave composed of dashes is proceeding to the right, the dotted one to the left. They have the same amplitude and wave-length. The solid line is the resultant of the former two.

At the start let us assume that the waves are completely out of phase as in (a). We know that the result will be a line of undisturbed particles. One-quarter of a period later (b), each will have shifted one-quarter wave-length but in opposite directions. The waves will be in phase now and will reinforce each other. For this reason, the resultant has wider amplitude than either of the original waves. Diagrams (c), (d), and (e), may be explained as above except that the phase is different after each quarter vibration. The combined effect is shown in (f).

Examination of the diagrams reveals that points 2, 4, 6, 8, 10 which are one-half a wave-length apart are always at rest and hence constitute the nodes. Points 1, 3, 5, 7, 9 move from rest to a point of maximum displacement on one side then back through the point of rest to a point of maximum displacement on the other and return. These are the loops.

Thus standing waves consist of nodes and loops. The distance between successive nodes or loops is one-half a wave-length. These waves will be useful in understanding vibrations in strings and air columns which will be presented in succeeding chapters.

II:7 REFLECTION OF SOUND WAVES

Sound waves travelling through the air and striking a smooth hard surface undergo reflection, obeying the same laws of reflection as light waves. That this is so can be demonstrated using the apparatus shown in Fig. 6:13. Sound

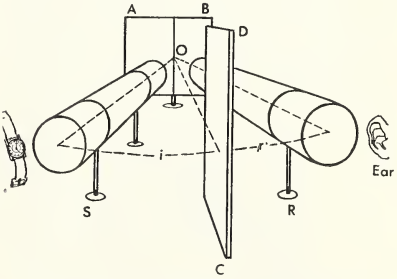


Fig. 6:13 Reflection of Sound.

waves from a source S (a watch) are directed by a tube to a hard surface, AB (a drawing-board is suitable for the purpose). A receiver, R (the ear), is

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placed at the end of a second tube which, to detect the signals, must be inclined to AB at the same angle as the first tube. In short, the angle of reflection (r) equals the angle of incidence (i). Also, the incident sound (SO), the perpendicular (CO) and the reflected sound (RO) are in the same plane. The screen CD acts as a shield to protect R from the sound waves transmitted directly from S.

A very interesting demonstration of the reflection of sound is found in the Museum of Science and Industry at Chicago. Two concave mirrors are arranged a long distance apart. A person standing at the focus of one may whisper softly and the words will be clearly audible to a person standing at the focus of the other.

Echoes are due to reflection. They are produced as the result of a sound

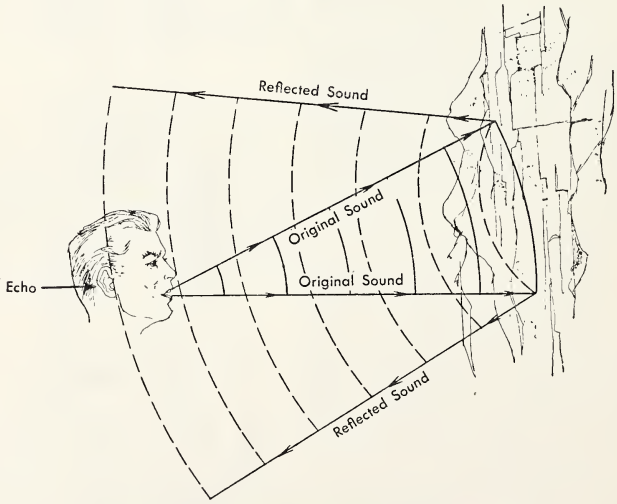


Fig. 6:14 The Production of an Echo.

signal directed towards a distant obstacle (e.g., a wall) being returned to the listener, who thus hears a repetition of the sound a short period after it has been produced. Forests, cliffs, hillsides, etc. will all reflect sound and cause the formation of echoes. If there are a number of reflecting surfaces at different distances from the source, a series of repetitions of the sound signal, each following the other, will be received. These are known as multiple echoes, and they are heard, for example, when an Alpine horn is blown amidst a number of mountain peaks.

The reflection of sounds may have unpleasant results in auditoria that are not properly constructed. The sounds echo and re-echo from the walls so that the effects of one sound have not died away before the next is made. The resulting jumble of sounds is known as **reverberation.**

Further reference to reflection of sound will be made in the next section and in section II:32.

II:8 THE VELOCITY OF SOUND

(a) Methods of Measuring

1. By Direct Measurement

The early experiments to determine the velocity of sound in air, made in the late seventeenth and early eighteenth centuries, were based on estimating the difference in time for the light and the sound to travel to an observer from a cannon fired some distance away (Fig. 6:15). Since the speed of light is very great (186,000 miles per second), the flash of the explosion is seen almost instantaneously. Hence the time elapsing between an observer seeing the flash and hearing the report of the explosion may be taken as the time needed for the sound to travel the measured distance between the cannon and observer, and this enables the speed of sound to be calculated.

There are two main objections to these simple "flash-bang" experiments. If there is a wind the result will be greater or less than the true value according to whether the wind is blowing from the cannon to the observer or in the opposite direction. The other chief source of error is the "reflex time" of the observer. Thus, if a stop-watch is used in such an experiment there is a difference between the response time in seeing the flash and starting the watch, and hearing the report and stopping it. This error varies with different observers, and with the same individual from time to time, and also even with the loudness of the sound. If the cannon is one mile from the observer the sound will take about 5 seconds to travel the distance, and hence a personal error of 1/5 second will introduce an error of four per cent in the final result.

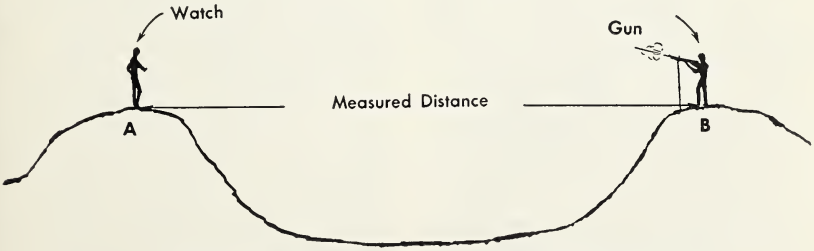


Fig. 6:15 Direct Measurement of Velocity of Sound.

The accepted values for the velocity of sound in air are tabulated below. It will be noted that for a change of 1 centigrade degree, there is a corresponding change in the velocity of sound in air of 2 feet per second or 0.6 metres per second.

TEMPERATURE	VELOCITY FT. PER SEC.	VELOCITY METRES PER SEC.
0°C.	1089	332
10°C.	1109	338
20°C.	1129	344

The first accurate determination of the speed of sound was carried out by the French Academy in 1738. Two cannons were used, separated by a distance of about 18 miles to reduce the error due to the "reflex time". To eliminate the effect of wind, timings were taken (by means of pendulums) in both directions and the average used to calculate the speed of sound. The result obtained was 337 metres per sec. at 6°C., or 332 metres per sec. at 0°C. Later experiments, carried out in the same way, but using chronometers, accurate to one-tenth of a second, gave a mean result of 331 metres per sec. at 0°C.

2. By Echoes

If a sound signal is directed to a distant wall or obstacle an echo will be received some time later, the sound wave having travelled twice the distance between the wall and the observer during the period. This suggests a possible method of measuring the velocity of sound. For clear echoes, however, the wall (or reflecting surface) should not be too far distant, and this involves the practical difficulty of measuring very short time-intervals. With a wall 100 yards distant, for example, the echo of a sound signal will be received only about one-half second later. This difficulty has been overcome by using a metronome or an electrically controlled tapper to send out a sequence of sound signals at regular intervals. The distance of the metronome from the wall is adjusted until the echo of one click is heard simultaneously with the next click. The sound signal has clearly travelled to and from the wall during the interval between the clicks. This time-interval is accurately known, and so the velocity of sound can be found. It should be noted that since the sound signal has to travel back along its track this method automatically eliminates the effect of the wind.

Example

A metronome was 280 feet from the wall and the time interval between clicks was 1/2 second.

Distance covered in 1/2 sec. was 560 feet

In 1/2 sec. sound has travelled 560 feet

In 1 sec. sound has travelled

$$\frac{1 \times 560}{1/2} = 1120 \text{ feet}$$

$\therefore$ the velocity of sound

$$= 1120 \text{ feet per sec.}$$

3. By Resonance

In section II:22, and experiment 10, chapter 10, we shall study resonance experimentally, and shall use the results in the formula $V = nl$ to determine the velocity of sound.

(b) Breaking the Sound Barrier

In recent years breaking the sound barrier, i.e., flying at the speed of sound (742.5 miles per hour at 0°C.) and more, has become a great test both of the skill of operation and the construction of aircraft. When an advancing craft catches up with its own sound waves a giant barrier of compressed molecules of air must be penetrated, and this requires the power of jet-type engines and an extremely strong construction of the aircraft. This situation

presents just one of the many practical problems which can only be dealt with because of our modern grasp of the nature of sound.

THE VELOCITY OF SOUND IN VARIOUS MEDIA

Medium	*Velocity*	
Gases	*feet per sec.*	*metres per sec.*
Carbon Dioxide (0°C.)	846	258
Oxygen (0°C.)	1041	317
Air (0°C.)	1089	332
Hydrogen (0°C.)	4165	1269.5
Liquids		
Water (9°C.)	4708	1435
Sea-Water (9°C.)	4756	1450
Solids		
Brass	11480	3500
Oak	12620	3850
Glass	16410	5000
Iron	16410	5000
Aluminum	16740	5104

II : 9 QUESTIONS

A

1. Which of the following statements is correct? (a) All vibrating objects produce sound. (b) All sound is produced by vibrating objects. Explain your answer fully.

2. (a) Distinguish between transverse and longitudinal vibrations.
(b) Define: complete vibration, amplitude, frequency, period.

3. (a) What is necessary for the transmission of sound?
(b) Compare the transmission of sound through the three states of matter and suggest a theoretical explanation for any differences.

4. (a) Distinguish between transverse and longitudinal waves.
(b) Define: amplitude, wave-length, period, frequency.
(c) By what type of wave-motion is sound transmitted? What are the components of each complete sound wave?
(d) What is the fundamental characteristic of wave-motion? Explain fully.

5. (a) Establish the wave formula.
(b) Calculate the velocity of sound in air if its frequency is 250 v.p.s. and its wave-length is 4.4 ft.

6. (a) What is meant by the terms "in phase" and "out of phase" as applied to any wave-motion?
(b) How are standing waves produced?
(c) Define: node, loop.
(d) Explain why the distance between two successive nodes is one-half a wave-length.

7. (a) State the laws of reflection of sound waves.
(b) Distinguish echoes and reverberations.

8. (a) In what three ways may the velocity of sound be determined?
(b) What is the effect of a change of

temperature on the velocity of sound in air?

9. The sound of a gun was heard 10 sec. after the flash was seen. If the distance to the gun was 11,500 ft., calculate the probable velocity of sound in air. Why is this merely a probable velocity?

10. Two and one-half seconds elapse between shouting across a river 1,375 ft. wide and hearing the echo from the opposite bank. (a) Find the velocity of sound. (b) Compare the accuracy of this velocity with that of question 5.

B

1. The horizontal distance between the end points in the swing of a pendulum is 7.5 cm. What is (a) the amplitude, (b) the distance covered by the bob in one complete vibration?

2. The pendulum in question 1 makes 45 complete vibrations in 30 seconds. Calculate the period of vibration. What would be the period if the amplitude were doubled?

3. Calculate the velocity of sound in air if the frequency of sound and its wave-length are (a) 180 v.p.s. and 6.50 ft., (b) 360 v.p.s. and 80.0 cm. respectively.

4. Calculate the frequency of a sound if the velocity and wave-length are (a) 1,120 ft. per sec. and 3.50 ft., (b) 340 metres per sec. and 51.0 cm.

5. What are the wave-lengths of the notes when (a) the frequency is 900 v.p.s. and velocity of sound 1,350 ft. per sec. and (b) the frequency is 625 v.p.s. and velocity of sound is 350 metres per sec.?

6. Calculate the velocity of sound in air in (a) feet per second and (b) metres per second at: 5°C., −17°C., 23°C.

7. At what temperature will the velocity of sound be (a) 1,119 ft. per sec. (b) 336 metres per sec.?

8. A thunder-clap is heard 5 seconds after the lightning-flash was seen. How far away was the flash if the temperature of the air were 15°C.?

9. When the temperature of the air is 15°C., calculate the wave-length in metric units of the sound from a tuning-fork having a frequency of 256 v.p.s.

10. When the temperature of the air is 25½°C., and the wave-length of a sound is 4.40 ft., calculate the frequency of the sound.

11. A signal of 128 v.p.s. has a wave-length of 279. cm. (a) Find the velocity of sound in air. (b) What would be the temperature of the air to the nearest degree centigrade? Express your answer in metric units.

12. The human ear is incapable of distinguishing individual sounds unless they are separated by a time interval of at least $\frac{1}{10}$ sec. (a) Calculate the length of the shortest auditorium that would give a distinct echo. (b) What would be the effect if the auditorium were shorter? (Assume that the temperature of the air is 20°C.)

13. A 220 yd. dash over a straight course was timed at 23.2 sec. What would the time have been had the timer started the watch on hearing the sound instead of seeing the flash? (Temperature of air = 20°C.)

14. Calculate the minimum speed of an aircraft in miles per hour which has broken the sound barrier. (Temperature of air = 5.5°C.)

CHAPTER 7 CHARACTERISTICS OF MUSICAL SOUNDS

II : 10 INTRODUCTION

(a) How a Musical Sound Differs from a Noise

As we have seen, people are quick to classify the sounds they hear, as either musical sounds or noises. Almost everyone finds noises, like the slamming of a door or the rumble of machinery unpleasant, and musical sounds like those of a tuning-fork or violin pleasant. We can establish a more objective difference than this between noise and music. When an oscilloscope is used to compare the sound of machinery and that of a tuning-fork, a trace similar

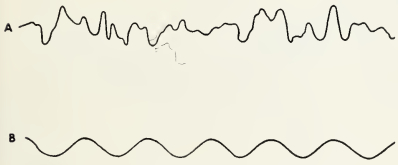


Fig. 7:1 Oscilloscope Tracing of
A—Noise
B—Musical Sound

to that in Fig. 7:1 results. It is obvious that the **musical sound** is caused by rapid regular (periodic) vibrations, while the **noise** is the result of irregular (non-periodic) vibrations.

(b) How Musical Sounds Differ from Each Other

If one tuning-fork is struck lightly, and another more vigorously, the second will emit a louder sound. Sounds that differ in loudness differ in **intensity**. If the sounds from two vibrating tuning-forks with differing frequencies are compared, the fork with the greater frequency emits the "higher" sound. Sounds that differ in "highness" differ in **pitch**. Further, if the sounds of a vibrating tuning-fork and a vibrating string of the same frequency are compared, there is no difficulty in identifying the origin of each sound. Sounds from different sources may be distinguished because they differ in **quality**. Thus musical sounds differ from each other in intensity, pitch and quality. It is the purpose of this chapter to study these three characteristics further.

II : 11 THE INTENSITY OF SOUND

If a bell that is rung cannot be heard at a distance, we know that we may be able to make it heard by striking it harder. This is so because striking with greater force transfers more energy to the vibrating body, increasing what we call the sounds. This increases the amplitude (energy of vibration) and gives it a greater intensity. If the sound is still inaudible, the other obvious thing that can be done to make it heard is

to shorten the distance between the source and the receiver. It might seem from this that there are just two factors affecting the intensity of sound, namely amplitude and distance, but the experience of undersea workers in caissons and diving-bells where the air is under great pressure, is that quite ordinary sounds are unexpectedly loud there. This greater intensity of the sound transmitted results from the fact that increased pressure on a gas crowds the molecules closer and increases the density of the medium. For the same reason, as is well known, sounds transmitted by solids and liquids are louder than when transmitted by air. Thus, a third factor affecting intensity of sound is density of medium.

The particular laws governing the intensity of sound are:

1. The intensity of sound varies directly as the square of the energy of vibration (amplitude) of the source.
2. The intensity of sound varies inversely as the square of the distance of the receiver from the source.
3. The intensity of sound increases with an increase in the density of the transmitting medium.

The intensity of sound is measured in bels and decibels (deci — 1/10), the decibel being the faintest sound that can be perceived by a normal human ear. Fig. 7:2 shows the amount of noise or "noise level" in decibels in a few common locations, for, like musical sounds, noises vary in intensity. Naturally, noises are inevitable wherever there is machinery, but unnecessary discomfort can be avoided by the noise level being measured and steps being taken to eliminate all unnecessary vibration. Noise levels around machinery can be reduced by the use of rubber mountings, mufflers and the like; walls and ceilings can be covered with sound-absorbent wallboard, and air-ducts with sound-absorbent baffles, while neighbouring buildings can be protected by double windows. The importance of such efforts to reduce

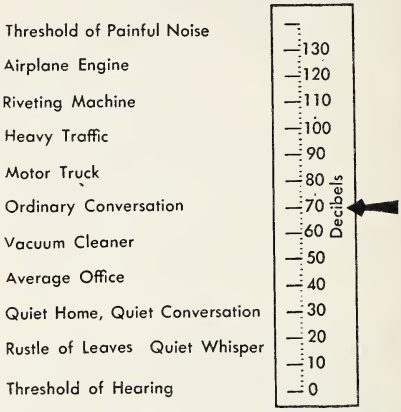


Fig. 7:2 Noise Levels.

noise levels is indicated by the fact that temporary or permanent deafness and many other illnesses can result from long proximity to noisy machinery.

II:12 THE PITCH OF SOUND

That musical sounds vary in highness or pitch was stated in a previous section. In chap. 10, exp. 6, Savart's toothed

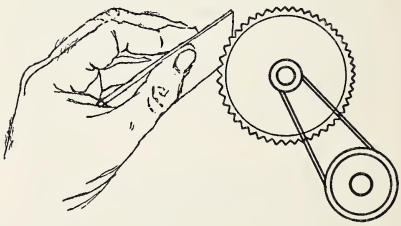
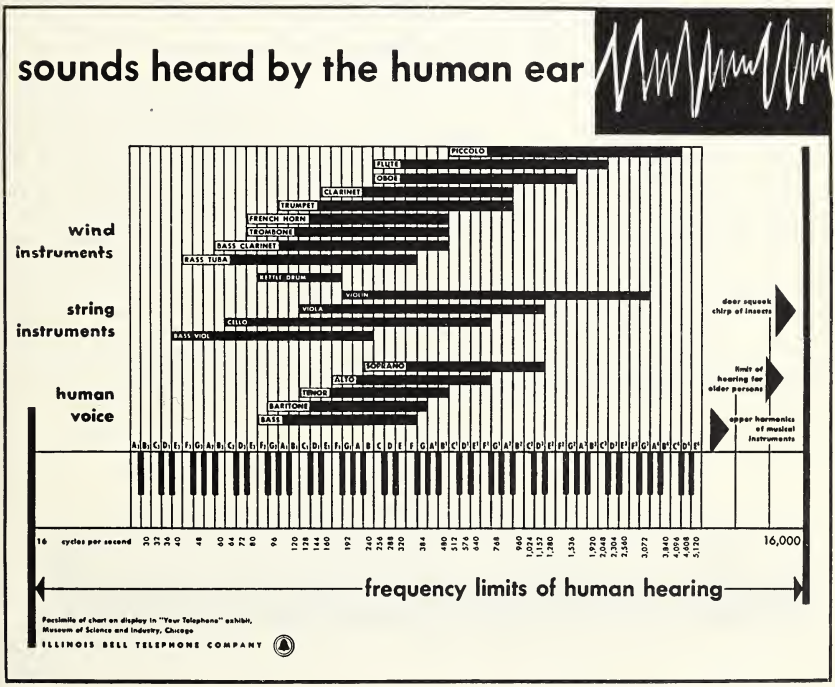


Fig. 7:3 Savart's Toothed Wheel.

wheel (Fig. 7:3) was used to show what determines pitch. The card held against the teeth of the rapidly rotating wheel received a sequence of taps, and a note, whose pitch increased with the speed of

rotation, was heard. If the rate of rotation was doubled, the number of taps per second (the frequency) was doubled. The second note, whose frequency is twice as great, is said to be an octave higher than the first. Thus for a note of high pitch to be sounded, the body must be vibrating rapidly, whereas a slow rate of vibration produces a note of low pitch. In short, the pitch of sound depends on the frequency. The frequency of the sound produced may be determined by applying the formula: *frequency of note produced (v.p.s.) = number of teeth on Savart's wheel × speed of rotation in revolutions per second.*

The limits of frequency for notes of audible pitch are from about 20 to 20,000 v.p.s. for the average ear (Fig. 7:4). The range of frequencies used in music is from about 30 to 5,000 v.p.s., the keyboard of a piano extending from 27 to 3,500 v.p.s. A man's speaking voice embraces frequencies ranging between 100 and 150 v.p.s. approximately. Extreme limits of audibility (for very sensitive ears) may be taken as extending from 20 to 35,000 v.p.s. The lowest notes of a large organ are in the neighbourhood of this lower audible limit, while the squeak of a bat or the noise of a cricket are examples of frequencies in the region of the upper audible limit. Frequencies above this point, referred to as ultrasonic frequencies, are becoming of increasing importance (Sec. II:33).



Bell Telephone Company of Canada.

Fig. 7:4 Frequency Limits of the Human Ear.

II : 13 THE DOPPLER EFFECT

When a car with its horn sounding approaches a pedestrian at high speed, the pitch of the sound appears to be higher than the true pitch which the driver hears (Fig. 7:5). After the car has passed, the pitch appears to be lower than the true pitch. Similar changes in pitch occur when the origin is stationary and the observer moves past it.

To determine the cause, let us take the case of the origin approaching the observer. In any second, a uniform number of wave-fronts are sent out and they will be a uniform distance apart. However, because the origin is approaching the observer, there will be more than the usual number packed in a given space, i.e., they will be closer together than before. As a result, more than the normal number will be received by the observer in one second. This will cause an apparent rise in the pitch of the sound. This phenomenon is called the **doppler effect**.

Fig. 7:5 The Doppler Effect.

II : 14 THE SONOMETER

In stringed instruments, the stretched strings of steel, gut, or silk, are set in a state of transverse vibration by being struck, bowed, or picked as in the piano, violin and guitar respectively. Examination of a piano and violin will reveal that sounds of different pitches are obtained by the use of strings of different lengths, tensions, diameters and densities. To ensure that the sound is loud enough to be distinctly heard, the string is attached to a sounding-box or board. The natural frequency of this is not that of the string but the string will set it in vibration with **forced vibrations** that will increase the volume of the sound.

The laboratory device embodying all these features is the sonometer shown in Fig. 7:6. It consists of a hollow wooden box (A) on which one or more strings (B) are stretched. Permanent (C) and movable (D) bridges and a means of varying the tension (E) are provided.

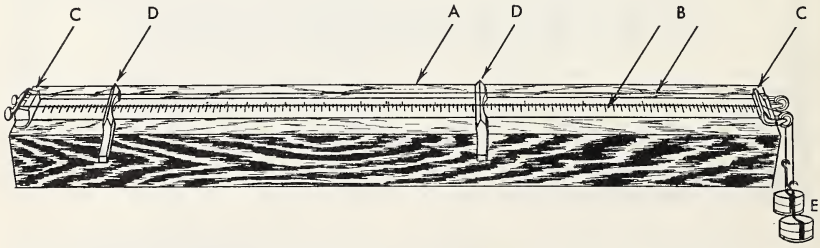


Fig. 7:6 The Sonometer.

We shall now proceed to use it to study the laws of vibrating strings.

II:15 THE LAWS OF VIBRATING STRINGS

(a) The Relationship between Frequency and Length

After doing experiment 7, chapter 10, results similar to those in the following table are found.

Examination of trials 1, 4 and 5 will show that while the frequency of 256 v.p.s. is emitted by 34.4 cm. of string, twice that frequency is produced by one-half that length and four times the frequency by one-quarter that length. Other possible results would be that three times the frequency is produced by one-third the length, five times the frequency by one-fifth, and so on. Thus we see, as in column 3 below, that the product of frequency times the length of vibrating string is constant within the limits of experimental error. Therefore, the frequency of the note produced by a vibrating string varies inversely as its length. This is the **law of lengths**.

RESULTS FOR LAW OF LENGTHS
Constant Tension = 3000 gm.

Frequency of Fork	*Length of Wire Producing Unison*	*Frequency × Length*
1. 256 v.p.s.	34.4 cm.	8806
2. 320 "	27.6 cm.	8832
3. 384 "	23.0 cm.	8832
4. 512 "	17.2 cm.	8806
5. 1024 "	8.6 cm.	8806

Example

If 30 cm. of wire at a certain tension produces a note with a frequency of 256 v.p.s., what would be the frequency when the length is 40 cm.?

Solution I

The ratio of the new length to the old $= \frac{40}{30}$

$\because$ the frequency varies inversely as the length.

$\therefore$ the new frequency is $\frac{30}{40}$ of the old.

$\therefore$ the new frequency $= 256 \times \frac{30}{40} = 192$ v.p.s.

Solution II

$\because$ the frequency varies inversely as the length, frequency $\times$ length is constant.

$\therefore$ the new frequency $\times$ the new length $=$ the old frequency $\times$ the old length.

Let the new frequency be x

$$\therefore x \times 40 = 30 \times 256 \qquad x = \frac{30 \times 256}{40} = 192$$

$\therefore$ the new frequency $= 192$ v.p.s.

(b) Relationship between Frequency and Tension

Adjust the length and tension of a string on a sonometer until it is in unison with a tuning-fork of frequency 256 v.p.s. Keeping a constant length of 25 cm., adjust the weights that stretch the string to get unison with a second, and then again to get unison with a third fork.

Record the results as follows, and from them determine the relationship.

Frequency of Fork	*Tension*
1. 128 v.p.s.	385 gm.
2. 256 v.p.s.	1540 gm.
3. 512 v.p.s.	6160 gm.

After comparing the results of trials 1 and 2, it is noted that twice the frequency is caused by four times the tension. A comparison of trials 1 and 3 shows that 4 times the frequency is caused by 16 times the tension. Since the multiplier for the frequency is the square root of the multiplier for the tension, it follows that the frequency of the note emitted by a vibrating string varies directly as the square root of the tension. This is the **law of tensions.**

Example

A string with tension of 2000 gm. produces a note with a frequency of 300 v.p.s. What would be the frequency of the note if the tension were 4500 gm.?

Ratio of the new tension to the old $= \dfrac{4500}{2000} = \dfrac{9}{4}$

$\because$ the frequency varies directly as the square root of the tension.

$\therefore$ the new frequency will be $\sqrt{\dfrac{4500}{2000}} = \sqrt{\dfrac{9}{4}}$ of the old

$\therefore$ the new frequency $= 300 \times \sqrt{\dfrac{9}{4}} = 300 \times \dfrac{3}{2} = 450$ v.p.s.

(c) Relationship between Frequency and Diameter

By an experiment somewhat analagous to (a) we may determine the **law of diameters,** i.e., the frequency of the note emitted by a vibrating string varies inversely as the diameter.

(d) Relationship between Frequency and Density

The **law of densities** states that the frequency of the note emitted by a vibrating string varies inversely as the square root of the density of the material.

All four laws may be illustrated by

examination of a violin. To increase the frequency of a note, the violinist shortens the string with his finger. When a violin is tuned, the tension is increased to increase the frequency and decreased to decrease the frequency. It will also be noted that those strings with greatest densities and diameters produce the lowest notes.

II:16 HOW A STRETCHED STRING VIBRATES

We have just considered the simplest mode of vibration of a stretched string wherein the string vibrates as a whole. There is a loop in the centre with a node at each end (Sec. II:6). When vibrating thus, the string is emitting the note of lowest frequency, the **fundamental**. However, the string may vibrate in other ways to produce notes of higher frequency (Chap. 10, Exp. 8).

When the string vibrates in halves, the note produced has twice the frequency of the fundamental and one-half the wave-length. This is the **first overtone** or **second harmonic**. When vibrating in thirds, quarters and fifths, the frequencies produced are three, four and five times that of the fundamental, and the wave-lengths are one-third, one-quarter and one-fifth of the fundamental. The notes are called the second overtone or third harmonic and so on. Fig. 7:7 shows some modes of vibration of a stretched string.

We see that a string may vibrate in parts, and as a whole as well. When it is vibrating in parts, the frequency of the note is a multiple of that of the fundamental and the notes are called the harmonics or overtones of the string. Frequently these overtones accompany the fundamental when that note is sounded, and give quality to the sound produced (Chap. 10, Exp. 9). Very few sources, on the other hand, produce the fundamental free of overtones. The tuning-fork is one that does, but even in it the overtones are present at the beginning of its vibration, vanishing as time goes on. It is this absence of over-

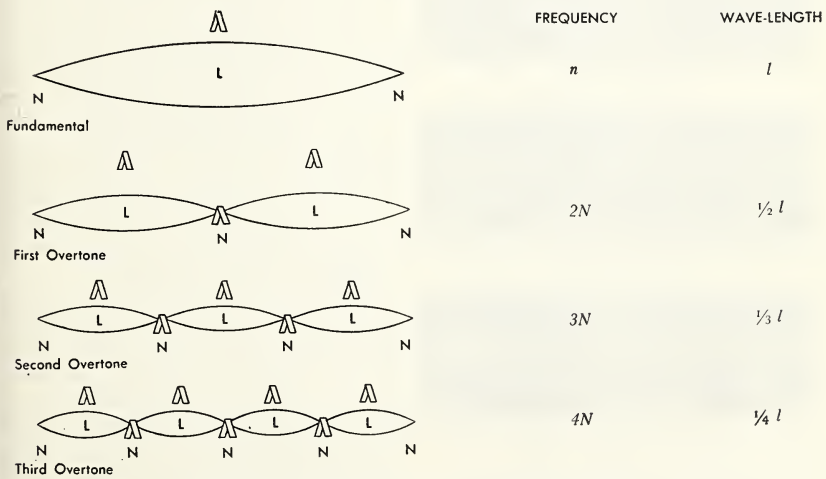


Fig. 7:7 Nodes and Loops in a Vibrating String.

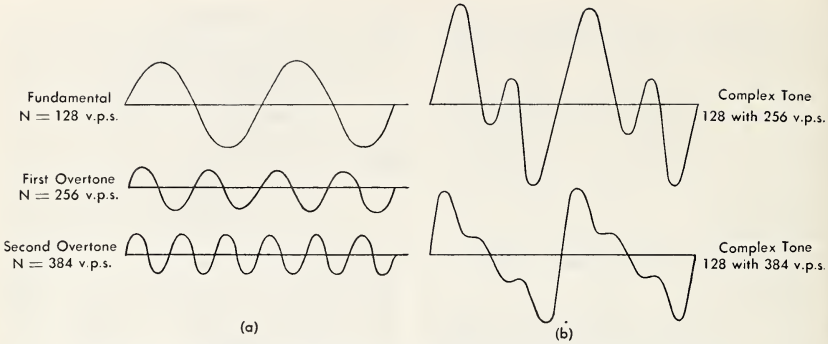
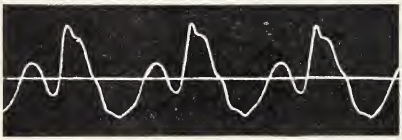
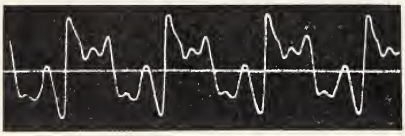


Fig. 7:8 Oscilloscope Tracings of Tuning Forks Sounded (a) Singly (b) Pairs

A—Tuning-fork



B—Organ Pipe



C—Clarinet

D—Violin

Fig. 7:9 Oscilloscope Tracings.

tones that makes the tuning-fork valuable in the study of sound, though at the same time it makes the note dull and uninteresting, for it is the overtones that make a note rich and interesting to the listener.

II:17 QUALITY OF SOUND

Let us analyse the vibration of a fundamental and its harmonics by means of a cathode-ray oscilloscope. If the fundamental has a frequency of 128, the first two overtones have frequencies of 256 and 384, respectively. Fig. 7:8 shows the results of sounding tuning-forks of these frequencies singly and in groups. When sounded singly, we see differences in frequency and wave-length of the notes. When sounded in groups, we see complicated wave forms which represent the blending of the fundamental and one or more overtones.

Next, with the aid of an oscilloscope, let us analyse notes from a tuning-fork and several other different sources having the same fundamental frequency. Fig. 7:9 shows several traces made in such a way. The regular trace of the tuning-fork indicates that it is emitting but a single tone. The complicated wave forms of the others indicate that:

1. They contain tones (overtones) in addition to the fundamental.
2. That some have more of these overtones than others.
3. That in some, the overtones are more prominent than in others.

We may conclude therefore that the **quality** of a musical note is dependent on the number and relative prominence of the overtones that occur along with the fundamental. It is the quality of the sound that enables us to distinguish notes of the same pitch and intensity from different sources.

II : 18 QUESTIONS

A

1. (a) Distinguish between a musical sound and a noise.
(b) What are the three distinguishing characteristics of musical sounds?

2. (a) Define intensity of sound.
(b) State three factors that affect the intensity of sound. Illustrate each with a suitable example.

3. (a) Define pitch.
(b) Describe an experiment to illustrate upon what the pitch of sound depends.
(c) Make up a set of observations and show how the frequency of a given note may be calculated.

4. (a) Describe the sound of a train whistle as the train moves rapidly away from you.
(b) Explain this phenomenon fully.

5. Describe a sonometer and state the purpose of each of its parts.

6. (a) State four factors that affect the frequency of a vibrating string.
(b) State the Law of Lengths. A stretched string 50 cm. long vibrates with a frequency of 150 v.p.s. What will be its frequency when the length is (i) 10 cm., (ii) 75 cm.?
(c) State the Law of Tensions. A stretched string of fixed length vibrates with a frequency of 125 v.p.s. when its tension is 900 gm. What will be its frequency when the tension is (i) increased to 2500 gm. (ii) decreased to 144 gm.?

7. (a) Describe an experiment to show the modes of vibration of vibrating strings.
(b) Define: fundamental, overtone.
(c) What governs the quality of a note?

B

1. A certain note has a frequency of 480 v.p.s.
(a) Determine the frequencies of notes that are one, two, and four octaves above the given note.
(b) Find the frequencies of notes that are one, three and five octaves below the note.

2. A toothed wheel with 40 teeth is rotated at the rate of 360 revolutions per minute while a card is in contact with the teeth. Calculate the frequency of the note heard.

3. A toothed wheel having 66 teeth is rotated while in contact with a card. What will be the speed of rotation in revolutions per minute when the frequency of the note produced is 352 v.p.s.?

4. How many teeth will a Savart's wheel have if the speed of rotation is 540 revolutions per minute and the frequency of the note produced is 1350 v.p.s.?

5. Savart's toothed wheels generally are arranged in sets of four on a common shaft with 12, 15, 18, 24 teeth respectively.

When rotating at the average rate of 21⅓ revolutions per second, they produce frequencies corresponding to C major chord at middle C on the piano, i.e., CEGC′. Determine the frequency of each note in the chord.

6. A stretched string 45.0 cm. long emits a note with a frequency of 300 v.p.s. What would be the frequency if the length became 15.0 cm., 60.0 cm., 20.0 cm.?

7. The A string of a violin vibrates at 440 v.p.s. The string is 40.0 cm. long from bridge to nut. If the violinist moves his finger so that only 30.0 cm. of the string vibrates, what will be the frequency of vibration?

8. A certain vibrating string 50.0 cm. long emits a note with a frequency of 320 v.p.s. What length of string would vibrate with the following frequencies: 640 v.p.s., 200 v.p.s., 457 v.p.s.?

9. A string 30.0 cm. long stretched by a weight of 4000 gm. emits a note having a frequency of 540 v.p.s. What would be the frequency if the stretching weight became 16000 gm., 1000 gm.?

10. A piano string is 60.0 in. long. It vibrates at 260 v.p.s. A piano tuner changes the tension from 25.0 lb. to 36.0 lb. What will be the new frequency?

11. A string 40.0 cm. long and having a tension of 1600 gm. emits a note of frequency 128 v.p.s. Determine the tension of this string when it vibrates with a frequency of: 64 v.p.s., 160 v.p.s.

12. A string 36.0 in. long under a tension of 16.0 lb. vibrates with a frequency of 256 v.p.s. What is the vibration frequency if the length is increased to 54.0 in. and the tension is increased to 81.0 lb.?

13. A string 100 cm. long under a tension of 4900 gm. has a frequency of 280 v.p.s. What is the frequency if the length is increased to 125 cm. and the tension reduced to 2500 gm.?

CHAPTER 8 RESONANCE AND INTERFERENCE PHENOMENA

II:19 THE MEANING OF RESONANCE

As resonance is a new idea, we shall find out what it means using the apparatus shown in Fig. 8:1. This consists of several pendulums attached to a cord tied between two supports. When one is vibrated transversely, the motion will be transmitted to the rest through the supporting cord. Any other pendulum

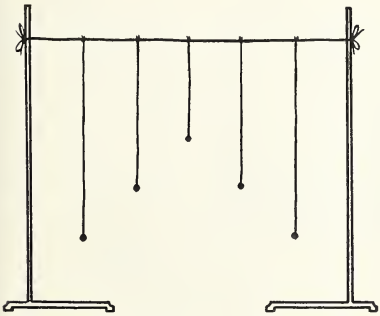


Fig. 8:1 Mechanical Illustration of Resonance.

of the same length and period of vibration will take up the vibratory motion and move with increasing amplitude. The others that have different periods will vibrate erratically, starting, stopping, but never accomplishing the persistence of vibration referred to above. Now, when impulses from one body affect another having the same period of vibration, the second will begin to vibrate with increasing amplitude. If it is already in motion, the amplitude will become greater. This effect is known as **resonance** and will be very valuable in explaining the phenomena that follow.

II:20 RESONANCE IN AIR COLUMNS

That air columns can be set in vibration and made to produce sounds of a definite pitch is well illustrated by such simple experiments as blowing across empty test-tubes of various lengths. Such air columns have a natural period of vibration depending on their length. If the fluctuations of pressure at the end of the column (caused by blowing) have the same period as that of the air column, resonance will occur. The column will be in a state of violent sympathetic vibration, and a strong note will be heard.

In our study of air columns, we shall use tubes of uniform cross-section. If the tube is closed at one end, it is called a closed tube, while if it is open at both ends it is designated an open tube.

(a) The Closed Tube

After performing the experiment to demonstrate resonance in a closed tube (Chap. 10, Exp. 10), let us consider

what occurred. When the sound that proceeds down the tube is reflected at the closed end the wave returns without change of phase. Thus a condensation is reflected as a condensation and a rarefaction as a rarefaction. As the sound arrives at the open end a change in phase occurs as follows: when a rarefaction reaches the open end some air is taken into the tube, and a condensation goes down the tube; when a condensation reaches the open end some air spills out of the tube and a rarefaction goes down the tube. Thus a condensation returns as a rarefaction, and a rarefaction as a condensation from the open end.

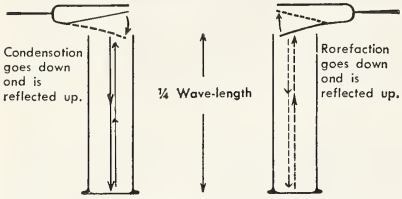


Fig. 8:2 Closed Tube in Resonance with Tuning-fork.

Fig. 8:2 shows a vibrating tuning-fork held over a closed air column which is in resonance with it. For greater simplicity we shall confine our attention to the movements of the lower prong, since movements of the upper one do not alter the final result. As the prong of the tuning-fork traces one-half a vibration, diagram (a), a condensation is sent down the tube and is reflected at the closed end as a condensation. When it reaches the open end it will be reflected down the tube as a rarefaction while the air that spills out forms a condensation that reinforces the condensation produced above the prong of the fork. If the length of the tube is such that the fork is about to execute the next one-half vibration, diagram (b), a rarefaction will go into the tube which tends to reinforce the rarefaction already proceeding downward. This process continues until the air in the tube is vibrating with such wide amplitude that it becomes the major source of the sound heard. It should be apparent that the sound travelled twice the length of the closed tube during one-half vibration, and therefore the length of the closed tube is equal to one-quarter of the wave-length.

(b) The Open Tube

Open tubes will also vibrate in resonance with sources of sound such as tuning-forks. It has been found that during one vibration the sound travels twice the length of the tube, and therefore the length of the open tube is equal to one-half of the wave-length. It will be evident, therefore, that the open tube that vibrates in resonance with a tuning-fork of a certain frequency is twice the length of the closed tube.

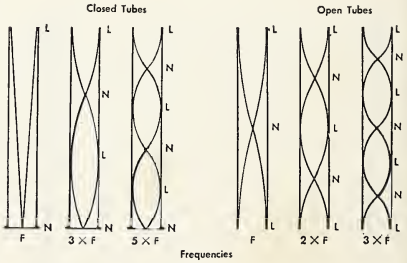


Fig. 8:3 Modes of Vibration in Air Columns.

II:21 MODES OF VIBRATION IN CLOSED AND OPEN TUBES

In vibrating air columns (Fig. 8:3), there will be nodes and loops (Sec. II:6). In the closed tube there will be

a node at the closed end and a loop at the open end. The length of closed tube will be one-quarter of a wave-length when it is responding to its fundamental tone. For the overtones, the distance from node to loop must also be one-quarter of a wave-length. After examination of the diagram, it will be evident that the closed tube can be in resonance with the overtones whose frequencies are odd-number multiples of that of the fundamental.

In the open tube there will be a loop at the open ends and a node will occur in the middle when in resonance with the fundamental. The length of the tube will be one-half a wave-length. For overtones, the tube must be capable of containing several half wave-lengths. Figure 8:3 shows how this can be done and makes it clear that the open tube can be in resonance with all the overtones.

II : 22 DETERMINING THE VELOCITY OF SOUND IN AIR BY RESONANCE IN AIR COLUMNS

(a) Closed Tubes

As explained in section II:20(a), the condensation travelled twice the length of the tube during one-half a vibration of the prong of the tuning-fork. Hence, sound must travel four times the length of the tube during one vibration of the prong. Since the distance energy travels during one vibration is one wave-length, the wave-length of sound must be four times the length of the closed tube which is in resonance with the tuning-fork. In actual practice, the true wave-length must be augmented by .3 times the diameter of the tube (see note) but for our purposes we may disregard it. Therefore, **wave-length (l) of sound = 4 × length of closed tube (L) giving resonance.**

Example

A tuning-fork whose vibration frequency is 256 v.p.s. produces resonance with a closed tube 13.0 inches long. Calculate the velocity of sound in air.

$V = ?$

$n = 256$ v.p.s.

$l = 4L$

$= 4 \times \dfrac{13.0}{12}$ ft.

$\because V = nl$ (Sec. II:5)

$\therefore V = 256 \times \dfrac{4 \times 13.0}{12}$

$= 1109$

$\therefore$ Velocity $= 1109$ feet per second

Since the measurements are accurate to three significant digits, the proper answer is 111×10 feet per second (Sec. I:3).

What would be the approximate temperature of the air in the above example?

(b) Open Tubes

In section II:20(b); it was stated that sound travels twice the length of the open tube during one vibration. Therefore, the **wave-length (l) of sound = 2 × the length of the open tube (L)** (see note).

Example

A tuning-fork whose vibration frequency is 1024 v.p.s. produces resonance with a tube 17.2 cm. long. Calculate the velocity of sound in air.

$V = ?$
$n = 1024$ v.p.s.
$l = 2L$
$= 2 \times 17.2$ cm.

$\because V = nl$
$\therefore V = 1024 \times \dfrac{2 \times 17.2}{100}$
$= 352.3$
$\therefore$ Velocity $= 352.3$ metres per second or 352 metres per second.

What would be the approximate temperature of the air in the above example?

Note In very accurate work a correction must be made for the change in pressure influencing the sound waves a short distance from the end of the tube. In a first course in physics, however, this factor need not be considered. For closed tubes, the end correction of $.3 \times$ the diameter of the tube must be added. For open tubes, you make the same correction for each end. The phenomenon is caused by the inertia of the air molecules.

II:23 SYMPATHETIC VIBRATIONS

Two tuning-forks of identical frequencies are mounted on hollow wooden boxes each open at one end (Fig. 8:4).

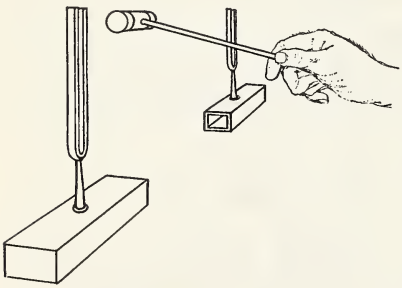


Fig. 8:4 Identical Tuning-forks to Illustrate Sympathetic Vibrations.

The size of the air column is such that its natural period of vibration is the same as that of the fork. The boxes are placed a short distance apart with their open ends facing each other. When one fork is vibrated and then silenced shortly afterwards, a sound of the same pitch is still heard (Chap. 10, Exp. 11.) It is found to originate from the other fork. This response of one body to the sound waves caused by the vibrations of another is called **sympathetic vibrations.** When a piece of plasticine is attached to the prongs of one fork its frequency is altered. If the above experiment were repeated this fork would not set up vibrations in the other. This shows that the two forks must have identical periods for sympathetic vibrations to occur.

Vibrations from the fork cause forced vibrations in the box and in turn the air in the box vibrates in resonance with them. The vibrations pass through the air to the other box, through the same sequence of events as above, but in reverse order, causing the second fork to vibrate.

II:24 INTERFERENCE OF SOUND WAVES

(a) Silent Points around a Tuning-Fork

When a vibrating tuning-fork is held vertically and rotated near the ear alternate loud and faint sounds will be heard (Chap. 10, Exp. 12). It will be found that the faint sounds are obtained when the tuning-fork is held cornerwise to the ear. To understand this phenomenon, we should recall that in transverse

vibration the prongs of the fork move together for half a vibration and apart for the next half. When they approach each other (Fig. 8:5) a compression

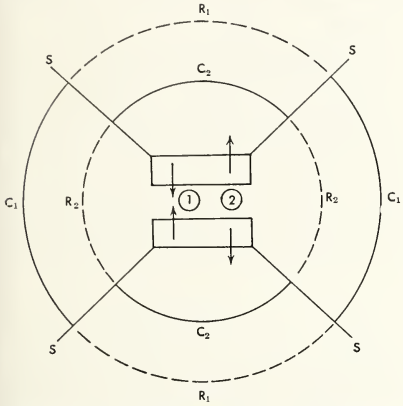


Fig. 8:5 Interference of Sound Waves around a Vibrating Tuning-fork

(C_1) is formed between them and a rarefaction (R_1) at either side. These two waves spread out in all directions and, because they are in opposite phase, interfere with each other, producing silence when they meet at the corners (S).

It is often noticed that the intensity of sound varies in different parts of an auditorium without any obvious cause. One possible reason for this is the interference of direct waves with reflected waves from walls and ceiling. If these are out of phase they will produce a faint sound as happened at the corners of the tuning-fork above. Another cause is discussed in Sec. II:30.

(b) The Herschel Divided Tube

Interference can be produced by dividing a wave disturbance into two parts, conducting each along a separate path, and then blending the two. This can be accomplished by the Herschel tube (Chap. 10, Exp. 13). It consists of two U-shaped tubes that telescope in and out of each other (Fig. 8:6). One side has a speaking-tube, the other an opening at which to listen. When a sound is sent in and the length of the two paths is adjusted, faint sounds are heard in some positions and loud ones at others. If the two paths that the sound follows differ by one-half a wave-length, or an odd number of half wave-lengths, the two parts of the sound will arrive out of phase at the observer and a faint sound will be heard. If the two paths are equal, or differ by a whole number of wave-lengths, the two parts of the

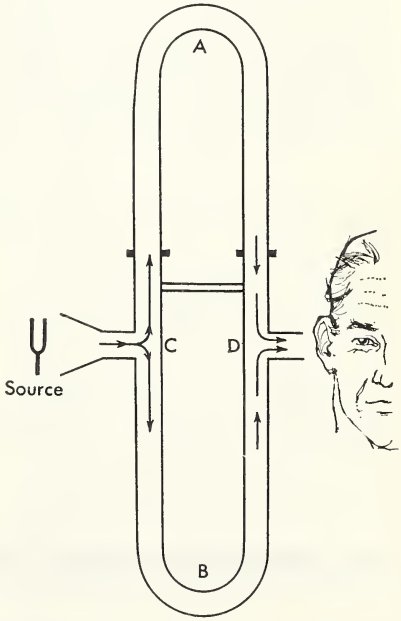


Fig. 8:6 The Herschel Divided Tube.

sound will arrive in phase at the observer and a loud sound will be heard. This phenomenon is used to find the wave-length of sound. If the frequency of the

note is known, the velocity of sound can be calculated.

(c) Beats

If the prongs of one of two middle C tuning-forks are loaded with plasticine, the frequency of its vibration will be slightly lower than that of the other. If these forks are sounded together, a sound will be heard which periodically increases and decreases in intensity. The alterations in the loudness of the sound are called **beats.**

Consider each of the waves sent out by the forks as transverse waves. By representing one with a solid line and the other by a dotted line, as in Fig. 8:7 (a), we see that they become progressively more out of step until one cancels the other. If the lines are continued they will eventually arrive in step, although one will be a wave-length in front of the other. Now, when waves are out of phase they interfere with each other with consequent reduction in amplitude of vibration or loudness of the sound. When completely out of phase there will be no movement and no sound. When completely in phase, there will be a greater amplitude and a louder sound. Between these extreme cases there will be a gradual increase or de-

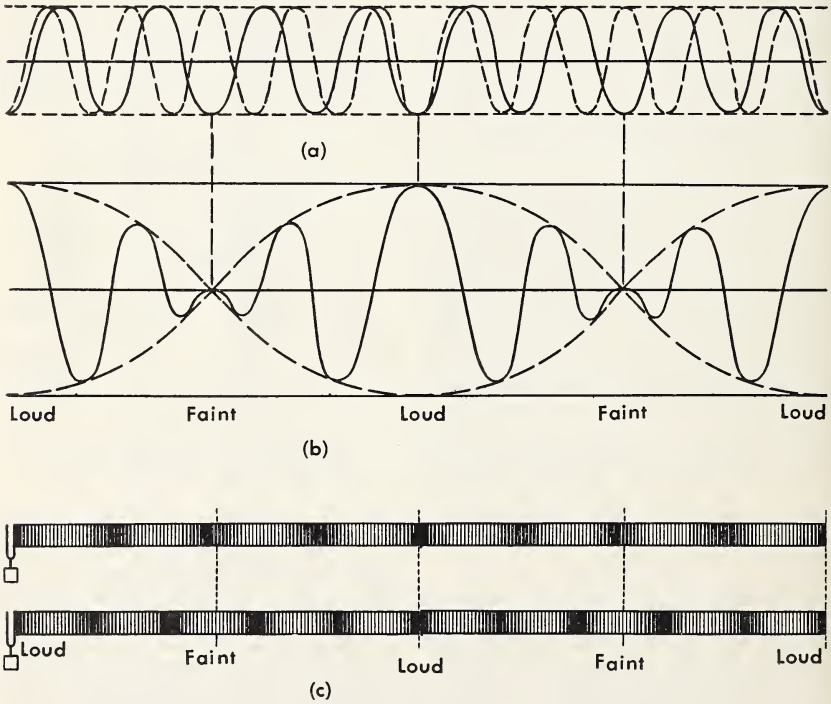


Fig. 8:7 Explanation of Beats.

crease in both amplitude and loudness. Fig. 8:7(b) shows the result of such interference.

Having studied beats with reference to transverse waves, we may understand their production in sound waves more easily. Fig. 8:7(c) shows two sound waves of slightly different frequencies being produced simultaneously. Assuming that they begin in phase, two condensations or rarefactions will occur together, producing a loud sound or a beat. As the two waves get out of phase, the sound will become fainter and the more out of phase they are, the fainter the sound will be. When completely out of phase, as when a condensation from one and a rarefaction from the other occur together, silence results. As they become progressively more in phase, the intensity increases until it reaches a maximum, at which point a loud sound or beat will occur as before. A repetition of this sequence of events gives us the effect noticed when two tuning-forks of slightly different frequencies are vibrated together.

If the forks being used had a difference in frequency of one v.p.s., one beat per second would result. Similarly, a difference of two v.p.s. would produce two beats per second and so on. In general, the number of beats per second equals the difference between the frequencies of the two notes. This provides a convenient means of determining the frequency of a sound. (How could this be done?) Moreover, musical instruments are tuned by listening for beats. The fewer the beats, the more nearly alike are the two frequencies. When unison is achieved, no beats may be discerned.

II : 25 QUESTIONS

A

1. (a) What is meant by resonance?
   (b) Explain resonance in closed tubes.
2. (a) A closed tube 12 in. long is in resonance with a tuning-fork whose vibration frequency is 300 v.p.s. Calculate (i) the wave-length of the sound (ii) the velocity of the sound in air.
   (b) What would be the length of a tube open at both ends that would be in resonance with the tuning-fork used in part (a)?
3. Explain and give examples of sympathetic vibrations.
4. (a) What is the cause of interference in sound?
   (b) Explain (i) silent points around a tuning-fork, (ii) variations in the loudness of sound as Herschel's divided tube is elongated.
5. (a) How are beats produced? Explain fully.
   (b) What determines the number of beats per second?
6. A person holds down the "loud pedal" of a piano and sings a note. Account for the humming sound heard. Why does more than one string respond?
7. Account for the sound produced by blowing across the top of an empty test-tube. What would be the wave-length of such a note?
8. Account for the rise in the pitch of sound heard as a cylinder is gradually filled with water.
9. Explain why a wavy sound is frequently heard when a tuning-fork mounted on a sounding-box, the open end of which faces a wall, is moved towards and away from the wall. Try it.

B

1. (a) Calculate the wave-length of a note that gives resonance with (i) a closed tube 15 in. long, (ii) an open tube 6 in. long. (Disregard the correction for diameter.)

   (b) Determine the velocity of sound in air if a tuning-fork ($n = 220$ v.p.s.) gives the results shown in question 1 (a).

2. Compare the frequencies to which a closed tube 12 in. long and an open tube of the same length will respond, the temperature of the air being 19½° C.

3. Find the frequency of a note that resonates with a closed tube 10.5 in. long, the temperature of the air being 15½° C.

4. Find the length of closed tube that will respond to a frequency of 288 v.p.s., the temperature of the air being 25½° C. Express the answer in both British and metric units.

5. A closed tube 4.0 ft. long responds to a frequency of 70 v.p.s. Find the temperature of the air.

6. A closed tube 40.0 cm. long responds to a frequency of 220 v.p.s. Find the temperature of the air.

7. A resonance box is to be made for a tuning-fork ($n = 440$ v.p.s.). When the velocity of sound in air is 330 metres per second, what would be the shortest length of box, closed at one end, that would resonate with it?

8. Two forks, having frequencies of 384 and 380 v.p.s. respectively, are sounded together. How many beats per second will be produced?

9. When a tuning-fork ($n = 480$ v.p.s.) is sounded with another of slightly different pitch and there are 6 beats per second, what are the possible frequencies of the second fork? How would you determine whether its frequency would be higher or lower than the other?

CHAPTER 9 APPLICATIONS OF SOUND

II:26 THE VOICE

Of all sources of sound the voice is the most wonderful. The vocal cords (c) in the larynx (Fig. 9:1) are two elastic membranes whose thickness, length

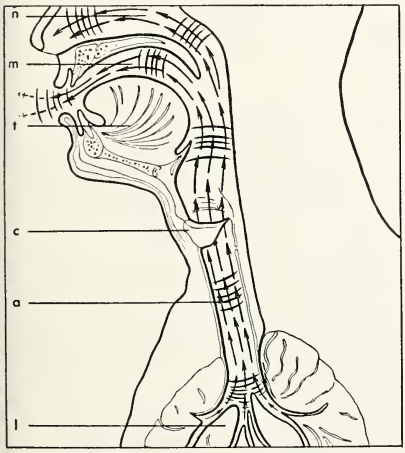


Fig. 9:1 The Human Voice.

and tension affect the pitch in response to the will of the person and in keeping with the maturity and sex of the individual. Air (a) from the lungs (l) passing between these membranes sets them in vibration in a way similar to blowing between the strands of a stretched elastic band. The faster the air moves, the greater is the intensity of the sound produced. The particular quality of the sound depends on resonance in the cavities of the mouth (m) and (n). Variations are caused by muscles altering the size and shape of these cavities. In the mouth, the tongue (t), in large measure, makes the major changes.

II:27 THE EAR

The ear is the most wonderful sound receiver that can be imagined. It consists of three parts: the outer ear, the middle ear, and the inner ear. Sounds are collected by the pinna (Fig. 9:2) and directed into the ear canal to the ear-drum. The ear-drum consists of a thin (3/1000 inch thick) tightly stretched membrane that is set in vibration by the sound waves and serves as the gateway to the middle ear.

Within the middle ear there are three bones named because of their shape, the hammer, the anvil and the stirrup. The hammer is in contact with the ear-drum, the stirrup with the oval window leading to the inner ear, and the anvil connects the two so that the vibrations of the ear-drum are transmitted to the inner ear. The middle ear is joined to the throat by the eustachian tube, the purpose of which is to equalize the air pressure on either side of the ear-drum.

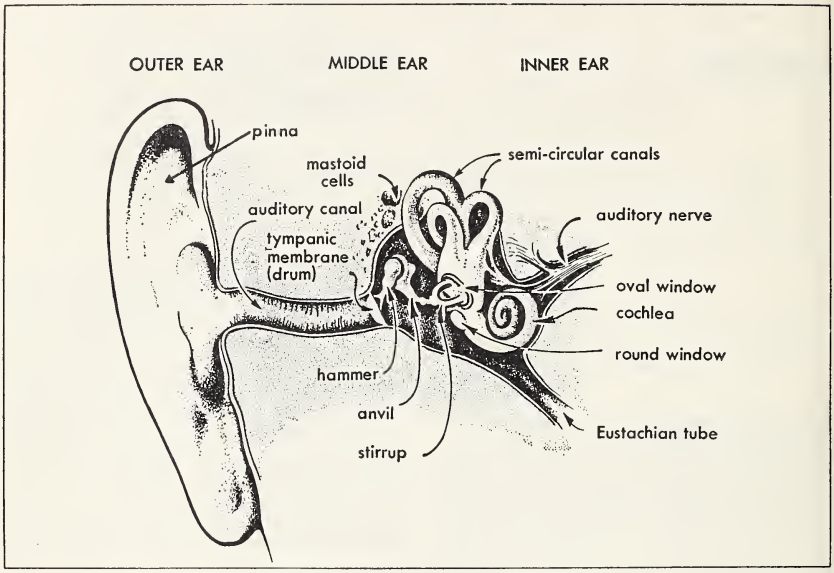


Fig. 9:2 The Human Ear.

This adjustment of pressure can be felt when motoring in hilly country.

The inner ear contains a spirally-shaped organ, the cochlea, containing a fluid which is agitated when the oval window vibrates. Movement in this fluid will cause hair-like projections to vibrate, transmitting small nerve impulses through the auditory nerve to the brain.

In addition to the cochlea, the inner ear contains another organ known as the semicircular canals, which is associated with posture and balance.

II:28 MUSICAL SCALES

The story of the evolution of the existing musical scale is a long and interesting one. The scale which gives maximum pleasure to us is one in which the frequencies of the notes are in the simple ratios shown (page 83). This scale is known as the **diatonic scale**, which on the tonic sol-fa corresponds to the notes doh, ray, me, fah, soh, lah, te, doh, or more familiarly perhaps, C, D, E, F, G, A, B, C′.

The first note on the scale is called the **tonic**, and the last note, of twice the frequency of the first, the **octave**. The number of the note (counting from the tonic) defines a musical interval on the scale; thus the interval from C to D is a second, that from C to E a third, and so on. These intervals correspond respectively to frequency ratios of

$$\frac{9}{8}\left(\frac{D}{C}=\frac{288}{256}\right),\quad \frac{5}{4}\left(\frac{E}{C}=\frac{320}{256}\right)\quad \text{etc.}$$

The last row of figures gives the ratios

THE DIATONIC SCALE

No. of note	1	2	3	4	5	6	7	8
Notation	C	D	E	F	G	A	B	C′
Absolute frequencies (scientific pitch)*	256	288	320	341.3	384	426.6	480	512
Frequency ratios	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Interval ratios	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$	

*In science C represents a frequency of 256 v.p.s. but for concert work however, C is usually tuned to 261 v.p.s.

of the frequencies between successive notes on the scale. These are known as the interval ratios, of which it will be seen that there are three. These are

$$\frac{9}{8}\left(\frac{D}{C}=\frac{288}{256}\right),\quad \frac{10}{9}\left(\frac{E}{D}=\frac{320}{288}\right),$$

$$\text{and}\quad \frac{16}{15}\left(\frac{F}{E}=\frac{341.3}{320}\right)\quad \text{etc.}$$

The ratios $\frac{9}{8}$ and $\frac{10}{9}$ are called major and minor tones respectively, those of $\frac{16}{15}$ being called **semitones.** The intervals between major and minor tones are too large for musical requirements and accordingly intermediate notes are inserted, known as sharps and flats. These are the black notes on the piano, the one between C and D, for example, being C sharp (C♯) or D flat (D♭).

A note is sharpened when raised by an interval of

$$\frac{25}{24}\ \text{e.g., C}\sharp=\frac{25}{24}\times 256=266.7\ \text{v.p.s.}$$

A note is flattened when lowered by an interval of

$$\frac{24}{25},\ \text{e.g., D}\flat=\frac{24}{25}\times 288=276.5\ \text{v.p.s.}$$

Thus on the diatonic scale C♯ and D♭ are not exactly equal in frequency. Further practical difficulties arise with the diatonic scale when changing from key to key—a process known as modulation. Thus in the key of D (the scale obtained using D as the tonic) it will be seen that intervals obtained using the white notes of the piano occur in a different sequence (minor tone, semitone, major tone, . . .) from those obtained when using the key of C (major tone,

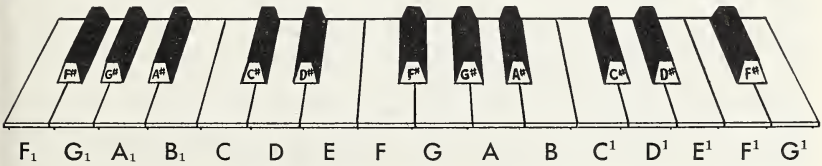


Fig. 9:3 The Piano Keyboard Showing Two Octaves of the Chromatic Scale.

THE SCALE OF EQUAL TEMPERAMENT OR THE CHROMATIC SCALE

Number of Note	1	2	3	4	5	6	7	8	9	10	11	12	13
Notation	C	C♯ D♭	D	D♯ E♭	E	F	F♯ G♭	G	G♯ A♭	A	A♯ B♭	B	C′
Absolute frequencies	256	271	287	304	323	342	362	384	406	431	456	483	512
Interval ratios	1.059	1.059	1.059	etc.									

minor tone, semitone, . . .). In order to correct this in all the various keys the number of "black" notes required would be very large indeed. This would make keyed instruments such as the piano and organ very difficult to play, although with the violin and the human voice, where a continuous range of frequencies is possible, there is no difficulty in producing the notes required.

The difficulty is overcome with instruments of fixed pitch by adopting a **scale of equal temperament** or **the chromatic scale** (Fig. 9:3) in which the differences in the intervals of the diatonic scale are abolished, the octave being divided into twelve equal semitone intervals each of which equals

$$1.059, \text{ e.g., } \frac{C\sharp}{C} = \frac{271}{256} = 1.059.$$

There is no difference between C♯ and D♭, etc., on this scale and difficulties of modulation are overcome. It should be noted that a small amount of discord is inevitably present in instruments of fixed pitch, such as the piano and organ, which are tuned according to this scale. Thus reference to the tables will show that a chord of the three notes C, E, G, which is known as a **major triad**, does not have exactly the desired frequency ratio 4: 5: 6 as on the diatonic scale. However, in spite of this imperfection, this scale meets all the requirements admirably.

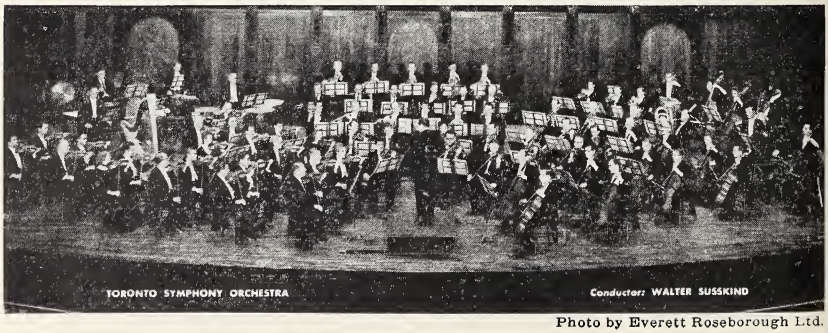


Photo by Everett Roseborough Ltd.

II:29 MUSICAL INSTRUMENTS

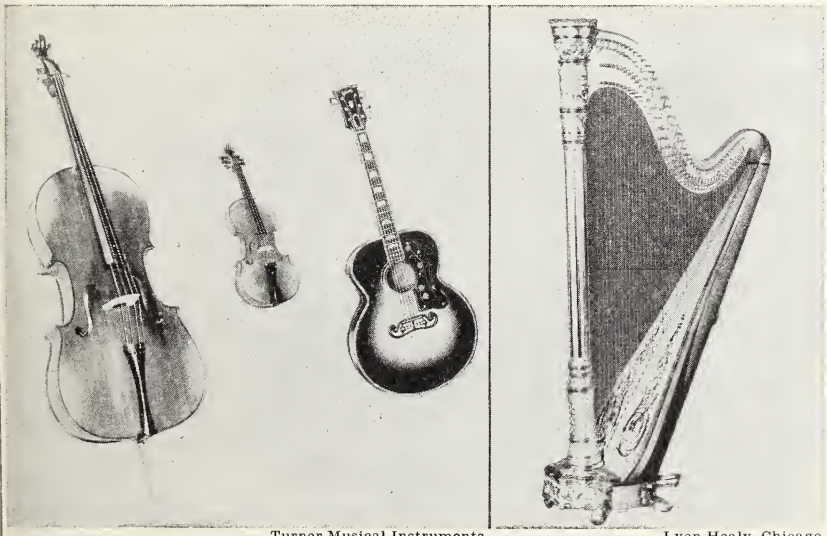
(a) Stringed Instruments

The reader will be able to suggest an extensive list of these (Fig. 9:4). All have a sounding-box or board over which one or more strings are stretched. This is made to vibrate at the same frequency as the vibrating strings to give greater intensity of sound. The frequencies of the notes emitted by the strings are determined by their lengths, tensions, diameters, and densities. Some instruments, e.g., the banjo-like group, have a fretboard to which the string is pressed, thus pre-determining the length required for a certain note. Those of the violin group have no frets and the performer must rely on his ear to obtain the desired note when he presses and vibrates the string. In the piano, there is a string of certain length, diameter, tension and density for each note. All stringed instruments produce notes with one or more overtones, their number depending on the manner of vibrating the string and the place where it is bowed, picked, or struck.

(b) Wind Instruments

These include the pipe and reed organs, the wood-winds and the brass instruments (Fig. 9:5). They involve a means of vibrating a resonant air column either of the open or closed variety. In some the air column is of fixed length and in others it may be varied by means of valves or a sliding telescoping device.

The closed pipe or flute type of pipe of an organ is pictured in Fig. 9:6(a). Compressed air (A) enters the space (C), is forced through the slit (S) and, on striking the lip (L), causes periodic variations in pressure. The length of the pipe is adjusted so that it resonates with these and gives out a musical tone, including overtones. Being a closed pipe,



Turner Musical Instruments — Lyon Healy, Chicago.

Cello Violin Guitar Harp

Fig. 9:4 Stringed Instruments.

Greene Music Co. Ltd

Fig. 9:5 Wind Instruments.

it has a node at the closed end and a loop at the open end and the sound contains the overtones whose frequencies are odd-numbered multiples of the fundamental. Owing to the greater number of higher overtones obtained with open pipes, organs generally contain that kind, but they have the disadvantage of being twice as long for a given note.

An organ pipe of the reed-type is pictured in Fig. 9:6(b). Here air (A) enters a metal-covered chamber (C) containing the stem of the pipe (S) with the reed (R). The note is determined by the reed and the air column serves to give resonance and improve the quality of the note.

Instruments such as the flute and piccolo are like the flute-type of organ pipe. Different notes are made by opening holes along the length of the air column. The saxophone, bassoon, clarinet, and oboe use a reed to set the air column in vibration, and the pitch is varied by opening and closing holes to vary the length of this column. In brass instruments the lips of the performer act as a double reed. Differences in pitch are produced by changing the length of air column with "valves" as in the cornet and similar instruments. This is accomplished by sliding the telescopic U-shaped part of the tube in or out as in the trombone, or by over-blowing to produce the overtones as in the bugle.

All musical instruments require frequent tuning due to mechanical defects or changes in temperature. Temperature affects not only the lengths of the strings in stringed instruments but the frequency of a resonant air column. The latter may be understood when we recall that the velocity of sound in air changes with the temperature. Since $V = nl$ and l is constant, then changes in V cause a corresponding change in n.

(c) Drums

There are several types of drums used in bands and orchestras (Fig. 9:7). The bass and snare drums and the tympani are some examples. They may have

either one or two "heads" made of calfskin or some similar material stretched over a metal or wooden shell, and are sounded by being struck with some form of drumstick. The first two types are used to give a "beat" to the music and certain other effects. The latter is tuned during a musical number to give a sound of low pitch in harmony with the orchestra. In each, the vibrations of the head are amplified through forced vibrations of the whole instrument.

(d) The Electric Organ

Electric organs are without pipes or air columns. The sounds are produced electrically by various means. In the Hammond Organ (Fig. 9:8), an iron "tone wheel" revolving near a magnet in a coil of wire generates alternating currents in the coil which, after they are amplified, give rise to sound in an amplifier. Many of these are required to give the whole range of frequencies.

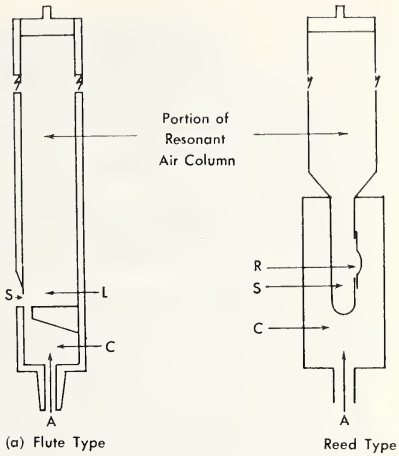
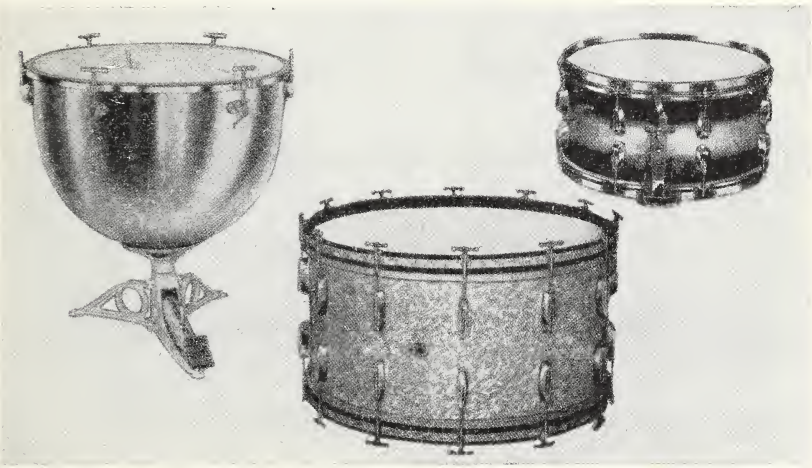


Fig. 9:6 Organ Pipes.

II:30 ACOUSTICS OF BUILDINGS

As was stated earlier, one of the difficulties encountered in the construction



Greene Music Co. Ltd.

Tympani Bass Snare

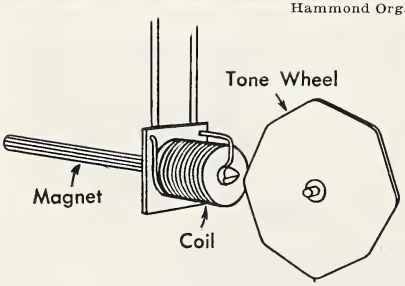
Fig. 9:7 Types of Drums.

Hammond Organ Western Export Corp.

Fig. 9:8

The Hammond Electric Organ.

(a) Organ.



(b) Sound Regulating Mechanism.

of auditoria is reverberation (Sec. II:7). As performers and speakers are entertaining bigger audiences in larger and larger halls, the study of reverberation has engaged the attention of acoustic engineers. Halls with too much reverberation are useless, those with too little are dead and uninteresting. Hence the aim is to achieve a happy medium (Fig. 9:9).

Reverberation may be reduced by various means including upholstered seats, the use of coffers or hanging drapes from arched roofs, curtains, tapestries and special acoustic wall finishes. Since the size of the audience would materially affect the acoustic qualities of an auditorium, upholstered seats with the absorbing power of one person, are employed. Thus ideal acoustics become

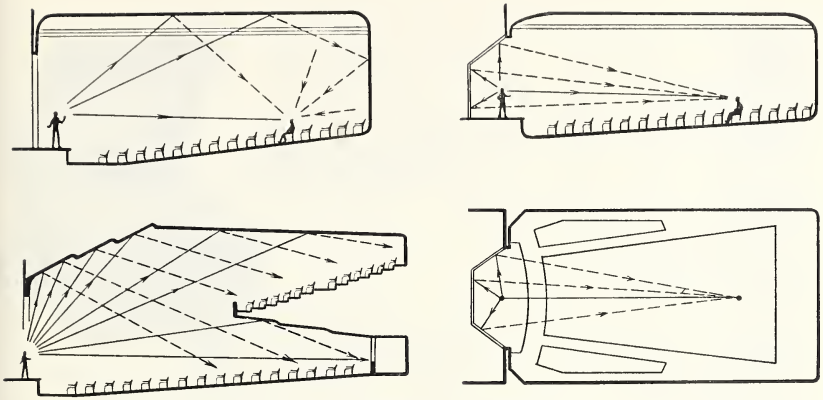
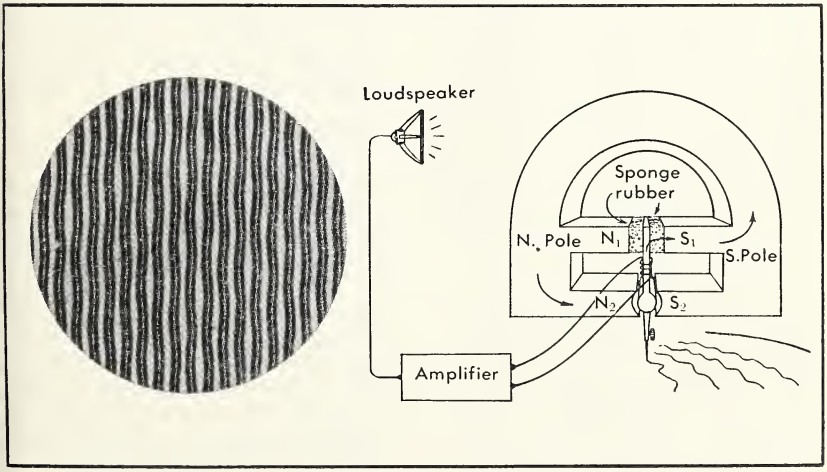


Fig. 9:9 Acoustics in Auditoria.

independent of the number of people present.

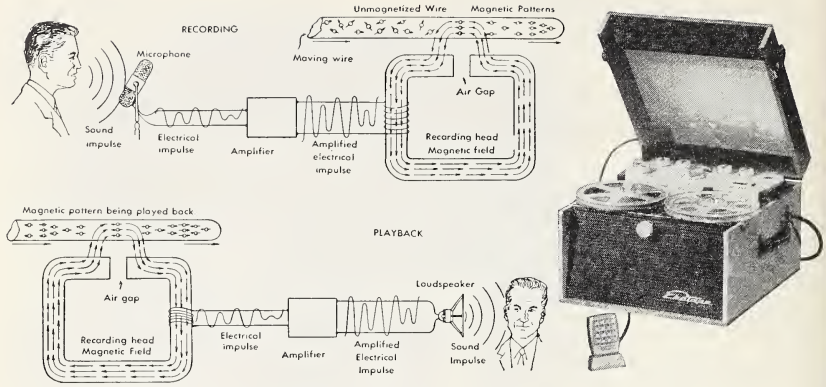
Focusing effects from curved surfaces often cause sounds of undesirable intensities at various places. Such effects may be reduced by acoustic finishes on walls or hangings of sound-absorbing material.

Outside noises frequently present acoustic problems. Street and hall noises may be reduced by double doors, and double or triple windows. Sound absorbent baffles in ventilating shafts will minimize sounds from that source. Machinery in the building may be mounted on rubber to absorb the vibrations. Buildings so protected should be free from outside noise.



A B

Fig. 9:10 A. Magnified Section Showing Grooves on a Recording.
B. A Sound Reproducer.



Dominion Sound Co. Ltd.

Fig. 9:11 Tape Recorder.

II:31 THE REPRODUCTION OF SOUND

The **Phonograph** was invented by Edison in 1877. He spoke into a tube which activated a sharp needle whose vibrations cut a straight groove of varying depth in a sheet of tin-foil. On the "play-back" another needle followed the groove and these up-and-down movements were transmitted to a diaphragm which set the air behind it in vibration. These early records were cylindrical. Later improvements suggested by Alexander Graham Bell, and others, included the use of a wax recording material, a disc-type record and a groove of constant depth which wavered from side to side, instead of a straight groove of varying depth.

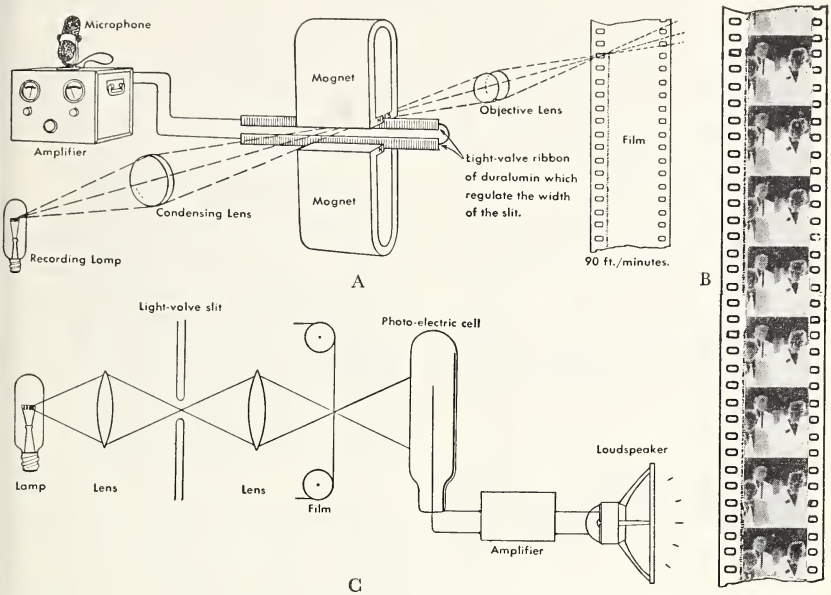
A simple diagram of the grooves on a modern record is shown in Fig. 9:10 (a), and of a modern reproducer in Fig. 9:10(b).

Recordings are cut by a steel needle (stylus) in a polished slab of wax. This is dusted with a powder such as graphite (an electrical conductor) then immersed in an electrolytic bath of bluestone, becoming copper plated on the passage of electricity through the bath. The slab emerges as a negative which is now reinforced by iron and is used to impress duplicates of the original on plastic discs.

The electrical reproducer transforms the vibrations of the needle as it follows the groove into electric currents which are amplified until they are able to activate a loudspeaker. Such reproducers make a sound more nearly like the original than did the former mechanical type.

Another form of recording of great use in music, in the office and in a host of other locations is the **tape recorder** (Fig. 9:11). The principle first used was to transform sounds into electric currents and use them, when amplified, to vary the magnetism in a wire. Later models used paper tape, coated with a thin layer of magnetic material. This has the advantage of being compact and can be readily edited. In addition, any recorded matter may be erased, permitting the same tape to be used many times.

Another type of sound recording is the **sound track** used on movie film



Film Strip: Rank Film Distributors of Canada Ltd.

Fig. 9:12 A. Recording Sound. B. Variable Density Sound Track. C. Reproducing Sound from the Track.

(Fig. 9:12). Sound is transformed into electric currents which are amplified so that the strength of two magnets can be varied. These magnets vary the width of a slit through which light passes from a source to the film. Such a film is said to be of the variable-density type. Reproduction from the sound track is accomplished by shining through it light from a source of constant strength to a photo-electric cell (Sec. V:82). As a result, the cell will produce a current of varying strength. This can then be amplified so that it is strong enough to operate a loudspeaker.

II:32 LOCATING UNSEEN OBJECTS

(a) Sound Ranging

Let us imagine that three receiving-stations S_1, S_2 and S_3 (Fig. 9:13) are located in carefully surveyed positions and an enemy gun is located at G. The times taken for each station to hear the

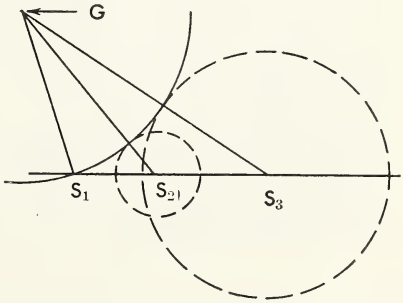


Fig. 9:13 Sound Ranging.

report are recorded and the differences are determined. Knowing the velocity of sound and the extra time required for the sound to get to S_2 and S_3, the respective distances from the gun (G) may be calculated (distance $= V \times t$). Construct a circle with centre S_2 and radius the calculated extra distance. Repeat for S_3. Construct a circle through S_1 and tangent to these other two. Locate its centre and that is the position of the gun.

(b) Sounding the Sea

In this process, a ship produces a sound (S) under water (Fig. 9:14) and receives it by a hydrophone (R) also

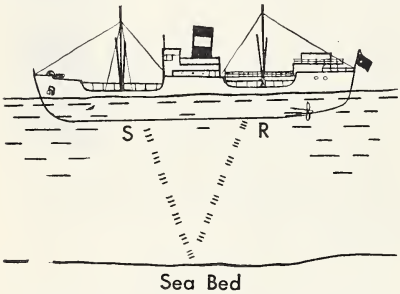


Fig. 9:14 Determining the Depth of the Sea.

under water. By means of a timing-device the interval may be determined. This must be halved when finding the depth of the sea. (Why?) Knowing the velocity of sound in water and the time, the depth can be determined.

The hydrophone is a special receiver for underwater work designed to respond to vibrations from one direction only. In time of war, it serves a useful purpose in locating enemy submarines.

For the source (S), it has been found best to use ultrasonic vibrations, i.e., having frequencies above the audible range. These can be beamed and on being detected are of such a nature as not to be confused with other vibrations in the water.

II:33 THE FUTURE OF SOUND

No one can foresee the future of sound. The properties of sounds in the audible range, that is, 20-20,000 v.p.s., are well understood. However, there is much to be learned about the ultrasonic vibrations whose frequencies are from 20,000 to 500,000,000 v.p.s. The dog whistle (20,000 v.p.s.) and the squeak of a bat (30,000 v.p.s.) are at the lower limit of this group of vibrations.

Some present uses for ultrasonic vibrations follow. When used at an intensity of 160 decibels or more they have been used to remove the dust and soot from chimney gases. During World War II Sonar (Sound, Navigation, and Ranging) was used at sea for sounding, locating submarines or other ships, and for underwater communication. Peacetime underwater uses include locating schools of fish and sunken ships. Another use is to cause molten metals to set more quickly, thus giving them finer grain structure and, thereby, greater strength. Conversely, it is used by large organizations to discover flaws in structural materials such as concrete. Still another is in homogenizing milk.

The physiological effects of these high-frequency sound waves are only beginning to be understood. Research is proceeding on measuring the body's tolerance to them, with a view to deriving possible curative values. Truly, the future of sound may be amazing!

II : 34

QUESTIONS

A

1. (a) Describe the larynx.
   (b) How do we produce sound in the larynx?
   (c) Give reasons for the varying quality of different voices.
2. (a) What are the three main divisions of the ear? Name the parts and purpose of each.
   (b) Describe how we hear.
3. (a) Define: tonic, octave, major tone, minor tone, semitone, major triad.
   (b) Distinguish between diatonic scale, and scale of equal temperament or chromatic scale.
4. Classify the instruments of a school orchestra under the headings: (a) stringed (b) wood-wind (c) brass (d) percussion. Give at least three examples of each.
5. Describe how the acoustics of lecture halls may be improved.
6. Describe several ways of recording sounds.
7. In sounding a lake, the time lapse between producing a sound and hearing the echo is 0.75 sec. The velocity of sound in water is 4750 ft. per sec. Calculate the depth of the lake at that point.
8. (a) Distinguish between the terms ultrasonic and supersonic.
   (b) Give several uses for ultrasonic vibrations.

CHAPTER 10 EXPERIMENTS ON SOUND

EXPERIMENT 1

To study transverse vibrations. (Ref. Sec. II:3)

Apparatus

A simple pendulum and support, stop-watch.

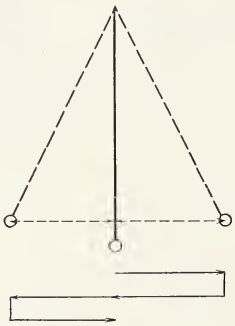


Fig. 10:1

Method

1. Attach the pendulum to the support. Draw the bob aside and let it swing freely.
2. With the bob at rest, mark its position by a chalk mark on the table. Draw the bob aside and measure the distance it travels to either side of the rest position.
3. While the bob is swinging measure the time required for 30 complete vibrations. Calculate (a) the number of vibrations per second and (b) the time required for one vibration.
4. Repeat part 3 using a greater and a smaller amplitude.
5. Repeat part 3 with a longer and a shorter pendulum.

Observations

1. (a) In the simple pendulum, what is the direction of motion relative to the length of the vibrating object?
   (b) What is one complete vibration?

2. How do the distances that the bob swings to either side of the rest position compare in magnitude?

3.	Time for 30 vibrations	The number of vibrations per sec.	The time for 1 vibration
The given pendulum			
The same with greater amplitude			
The same with smaller amplitude			
The pendulum made shorter			
The pendulum made longer			

Conclusions

1. (a) What type of vibratory motion is illustrated by the pendulum? (b) Define complete vibration.
2. Define amplitude of vibration.
3. Define (a) frequency of vibration, (b) period of vibration.
4. What effect has changing the amplitude on the frequency and period of vibration?
5. What effect has changing the length of the pendulum on its frequency and period?

Questions

1. Why do we call these vibrations transverse?
2. What changes take place in amplitude as the body is allowed to vibrate for a long time? What effect has this on the period or frequency of vibration?
3. Why is the period not dependent on the amplitude?
4. Why is the pendulum a suitable device for controlling a clock?

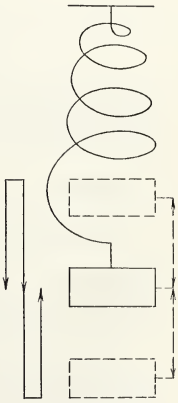


Fig. 10:2

EXPERIMENT 2

To study longitudinal vibrations.

(Ref. Sec. II:3)

Apparatus

A coil spring, weight, support, stop-watch.

Method

1. Suspend the weight from the support by the coil spring. Draw the bob down and release it.

2. When the weight is at rest, mark its position by a chalk mark on some vertical object such as a ruler. Draw the weight down and note the distance that it travels above and below the rest position.
3. While the weight is moving measure the time required for 30 complete vibrations. Calculate (a) the number of vibrations per second and (b) the time required for one vibration.

Observations

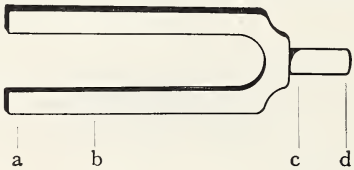
1. (a) In the coil spring what is the direction of motion relative to the length of the vibrating object?
   (b) What is one complete vibration?
2. How do the distances that the weight moves to either side of the rest position compare in magnitude?
3. (a) What is the number of vibrations in 30 seconds?
   (b) What is the number of vibrations in one second?
   (c) What is the length of time for one vibration?

Conclusion

1. What type of vibratory motion is illustrated by the coil spring?
2. Give the meaning of the terms complete vibration, amplitude, frequency and period.

Questions

1. Why do we describe these vibrations as longitudinal?
2. What would be the mode of vibration of a tuning-fork at a, b, c, d? Test your answers by exploring the fork with a pith ball.



EXPERIMENT 3

To determine whether or not sound requires a material medium for its transmission. (REF. SEC. II:4)

Apparatus

Bell-in-vacuo (Fig. 6:5), exhaust pump, wax or vaseline, electric wires, two dry cells, switch.

Method

1. Seal the bell-in-vacuo onto the pump plate with the wax and connect with the exhaust pump. Connect the bell, cells and switch. Close the switch.
2. Start the pump and gradually evacuate the jar.
3. Stop the pump and let the air slowly return.

Observations

What changes in loudness are observed?

Conclusion

What would you be led to conclude about the ability of sound to be transmitted in the absence of a material medium?

Questions

1. Why was sound not entirely eliminated?
2. What changes in the apparatus would improve this experiment?
3. What effect does changing the density of the medium have on the transmission of sound?
4. Verify your answer to question 3 experimentally, using different media, e.g., wood, water and air, between your ear and a sounding object, e.g., a waterproof watch.
5. Does light require a material medium for its transmission?

EXPERIMENT 4

To illustrate the different kinds and fundamental characteristics of wave motion. (Ref. Sec. II:5)

Apparatus

A length of rubber tubing, a long coil spring, two rigid supports.

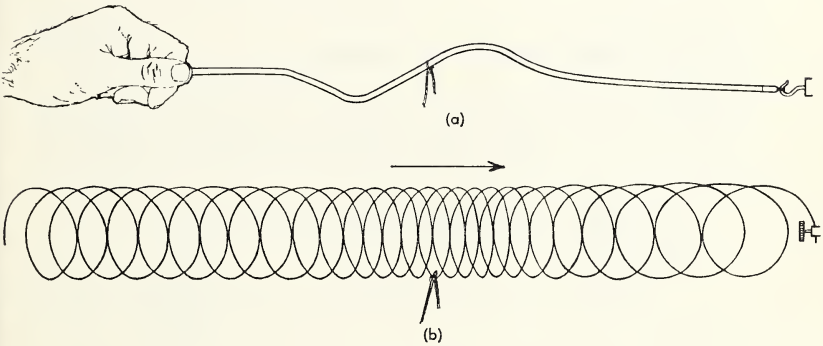


Fig. 10:3

Method

1. Tie one end of the rubber tubing to one of the supports. Tie a piece of string to the tube, leaving one end dangling. Vibrate the free end of the tube up and down with the hand. Note the effect of the vibration on the tube.
2. Attach the coil spring between the two supports. Tie a piece of string to it as in part (1). Squeeze several coils together and release them. Note the movements of the string.

Observations

1. (a) What is observed when the end of the tube is vibrated?
   (b) What is the direction of the motion of the particles of the tubing relative to the length?
2. (a) What is observed when the coils of the spring are released?
   (b) What is the direction of motion of the coils of the spring relative to the length?

Conclusions

1. What are the two parts of transverse waves? Define and give examples of transverse wave-motions.
2. What are the two parts of a longitudinal wave? Define and give examples of longitudinal wave-motion.
3. Define: crest, trough, condensation, rarefaction, wave-train.
4. How is the energy from the source of disturbance transmitted through a medium?
5. What is the fundamental characteristic of wave-motion?

Questions

1. What is the meaning of wave-length, the amplitude of the wave, the frequency of the wave, the period of the wave?
2. Establish the relationship between velocity, frequency and wave-length.

EXPERIMENT 5

To show standing waves in a stretched cord. (REF. SEC. II:6)

Apparatus

Electric bell with gong removed, rigid stand and clamp, pulley and support, pan, with weights, length of light silk cord, batteries, connecting wire.

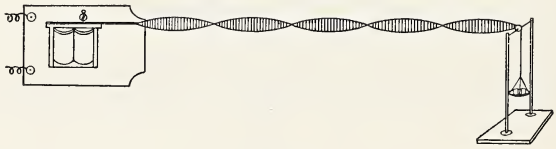


Fig. 10:4

Method

Tie one end of the cord to the clapper of the bell and the other to the pan of weights. Assemble the apparatus as in diagram and close the circuit. Adjust the tension of the cord by changing the weights on the pan until the cord takes up a steady appearance.

Observations

1. What effect has the clapper on the cord?

2. What happens to this disturbance when it reaches the support at the distant end of the cord?
3. What is the appearance of the cord?

Conclusions

1. What causes standing waves in a stretched cord?
2. Define: node, loop. Explain the cause of each.

EXPERIMENT 6

To show what determines the pitch of sound. (Ref. Sec. II:12)

Apparatus

Savart's toothed wheel, rotator, cardboard card.

Method

1. Assemble the apparatus as in Fig. 7:3 and rotate the disc while holding the card against it. Note the pitch of the sound produced.
2. Repeat part 1 while rotating the disc at a slower rate.
3. Repeat part 1 while rotating the disc at a faster rate.

Observations

What is observed in each of the above parts?

Conclusion

What determines the pitch of sound?

Questions

1. How would you determine the frequency of the note produced in the above experiment?
2. What is the frequency of the note an octave higher than another?
3. What kind of sound would have been produced by a disc with irregularly spaced teeth? Explain.

Note Experiment 6 may be done using a perforated disc and a jet of compressed air.

EXPERIMENT 7

To determine the law of lengths for vibrating strings.
(Ref. Sec. II:15)

Apparatus

Sonometer (Fig. 7:6), one steel string, movable bridge, tuning-forks with different frequencies such as 256, 320, 384, 512, 1024 v.p.s.

Method

1. Using a string 100 cm. long, adjust its tension until the pitch of sound that it produces is the same as that of the fork whose frequency is 256 v.p.s. Record the frequency of this note and the length of string that produces it in the table below.
2. Without changing the tension, adjust the length of the string by

inserting the movable bridge beneath it. Determine the lengths of string that will produce notes of the same pitch as the other forks provided. Tabulate these frequencies and lengths.

Observations

1. What length of string produces a sound of low frequency?
2. What change in frequency of sound occurs as the string is shortened?
3. *Table of Results.*

FREQUENCY OF NOTE	LENGTH OF STRING	RATIO OF FREQUENCIES	RATIO OF LENGTHS	PRODUCT OF FREQUENCY AND LENGTH OF STRING
256 v.p.s.	100			
320 v.p.s.				
384 v.p.s.				
512 v.p.s.				
1024 v.p.s.				

Explanation

1. What is true of the ratio of the frequencies compared to the ratio of the lengths?
2. What is true of the product of the frequency of the note times the length of the string producing it?

Conclusion

State the law of lengths for vibrating strings.

Questions

1. In the above experiment, what length of string would have a frequency of 768 v.p.s., 128 v.p.s.?
2. In the experiment, what frequency would be produced by a string of length 150 cm., 20 cm.?
3. In part 1, what effect does changing the tension have on the frequency of the note produced?
4. List two factors that affect the frequency of a note produced by a vibrating string.

EXPERIMENT 8

To illustrate the modes of vibration of vibrating strings.
(REF. SEC. II:16)

Apparatus

Sonometer, one steel string, bow, several V-shaped paper riders.

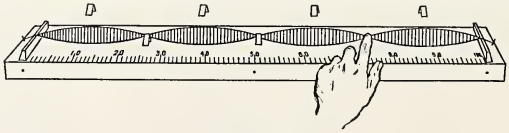


Fig. 10:5

Method

1. Place three paper riders at equal intervals along the string. Bow the string at its centre and note the effect on the riders and the pitch of the note produced. Record your results in the table.
2. Place three riders on the string as before. Touch the string lightly at its centre and bow the string in the middle of one of the halves. Make the same observations as before and tabulate them.
3. Repeat part 2 using five riders, touching the string one-third of its length from one end and bowing in the middle of this third.
4. Repeat using seven riders, touching the string one-quarter of its length from one end and bowing in the middle of this quarter.
5. Repeat using nine riders, touching the string one-fifth the length of the string from one end and bowing in the middle of this fifth.

Observations

Position of Damping	Effect on Riders	Diagram to Show Mode of Vibration of String	Frequency of Note Produced
1. None			
2. 1/2			
3. 1/3			
4. 1/4			
5. 1/5			

Conclusions

1. What is the manner of vibration of a vibrating string when producing its fundamental? Its various overtones?
2. What are the frequencies of the various overtones compared to that of the fundamental?
3. Define: fundamental, overtone.

Question

How do you account for differences in quality of the same note from various sources?

EXPERIMENT 9

To study the effect of the superposition of waves on the quality of sound produced. (Ref. Sec. II:17)

Apparatus

Four tuning-forks ($n = 256$, 320, 384, 512 v.p.s.), rubber mallet, hard mallet, bow, tuning-fork on resonance box.

Method

1. (a) Vibrate each tuning-fork separately by striking it with the rubber mallet and note the quality and pitch of the sound produced by each.

(b) Vibrate the forks, $n = 256$ v.p.s. and 320 v.p.s., simultaneously and note the quality of the note.

(c) Repeat part 1 (b) using the fork, $n = 256$ v.p.s., and with one, two or three of the others.

2. (a) Bow the tuning-fork on the resonance box and observe the quality of sound produced.

(b) Vibrate the same fork by striking it with the hard mallet and again note the quality of sound produced.

(c) Vibrate the same fork by bowing it and striking it with the hard mallet simultaneously. Note the quality of this sound.

Observations

What is observed in the above parts of the experiment?

Conclusions

1. What determines the quality of sound?
2. Explain in terms of superposition of waves.

EXPERIMENT 10

To demonstrate resonance in a closed air column and to find the velocity of sound in air. (REF. SEC. II:20)

Apparatus

Retort stand, clamp, cylinder, water, open tube about 15 inches long, several tuning-forks (256, 384, 512 v.p.s.).

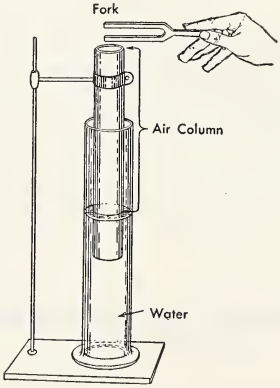


Fig. 10:6

Method

1. (a) Fill a tall glass jar with water at room temperature to the three-quarter mark and place a smaller glass tube, open at both ends, in the water as shown. This tube should be clamped to a retort stand so that it may be raised, lowered or secured at will. Sound a tuning-fork ($n = 256$ v.p.s.) and hold it close to the open

end of the tube. Raise or lower the tube until a position is found where the air column resounds most loudly. Measure the length of the air column.

(b) Repeat (a) with the other tuning-forks.

Observations

1. What was the room temperature?
2. What is observed when the tuning-fork is brought to the top of the tube before and after adjustment of the length?
3. *Table of Results.*

Frequency of Fork	Length of Closed Tube in Resonance
256	
384	
512	

Explanation

What is the cause of resonance?

Calculations

1. What is the wave-length of the note produced by each tuning-fork?
2. Calculate the velocity of sound in air from the result obtained for each fork and average your answers.

Conclusions

1. What is resonance?
2. What is the average velocity of sound in air?

Questions

1. From the temperature recorded during the experiment, calculate the velocity of sound in air and compare it with the experimental value.
2. Determine the percentage error in your experimental result.
3. What is the relationship between the length of vibrating air column and the frequency of fork that gives resonance?

EXPERIMENT 11

To study the production of sympathetic vibrations. (Ref. Sec. II:23)

Apparatus

Two matched tuning-forks mounted on resonance boxes (Fig. 8:4), rubber mallet, wax or plasticine.

Method

1. Place the tuning-forks close together with the open ends of the boxes facing each other. Strike one fork and silence it after a short time. Note what happens.
2. Strike the other fork and repeat part 1.

3. Load the prongs of one of the forks with wax or plasticine. Sound the forks separately. What is observed?
4. Repeat parts 1 and 2 using the forks as they are now. What happens?

Observation

State your observations for each part above.

Explanation

Account for your observations.

Conclusions

1. What are sympathetic vibrations? 2. Explain their cause.

Questions

1. What would occur in this experiment if one fork were an octave higher than the other? Try it, and explain.
2. Suggest other examples of sympathetic vibrations.

EXPERIMENT 12

To illustrate interference of sound waves by means of a study of silent points round a vibrating tuning-fork.

(REF. SEC. II:24(a)

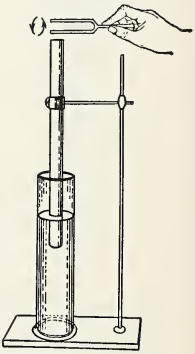


Fig. 10:7

Apparatus

A tuning-fork, rubber mallet, closed air column as in experiment 10.

Method

1. Vibrate the tuning-fork and hold it over the closed air column. Adjust the length of the column until resonance results.
2. Now slowly rotate the vibrating tuning-fork while holding it above the air column and observe.

Observations

Note the changes in the intensity of the sound heard and the position of the tuning-fork for each change.

Explanation

With the aid of a diagram account for these changes.

Conclusion

What is meant by interference of sound waves?

EXPERIMENT 13

To illustrate the interference of sound waves by the use of Herschel's divided tube. (Ref. Sec. II:24(b)

Apparatus

Tuning-fork, rubber mallet, Herschel's divided tube (Fig. 8:6), rubber hose and ear-trumpet.

Method

1. Adjust Herschel's tube so that the two paths C A D and C B D are equal. Hold a vibrating tuning-fork in front of the opening C and listen at the ear-trumpet joined to D.
2. Gradually draw out A and note the positions of minimum and maximum loudness of sound. Measure the difference in lengths of the two paths for each such position. Tabulate your results.

Observations

1. Describe carefully what is heard.
2. *Table of Results.*

Intensity of Sound	Difference in Lengths of Paths (C A D-C B D)
(1) Maximum	
(2) Minimum	
(3) Maximum	
(4) Minimum	

Explanation

1. Account for the variations in the intensity of sound heard.
2. How could the wave-length of the note be calculated?

Calculation

Calculate the wave-length of the note.

Conclusion

How does Herschel's divided tube illustrate interference of sound waves?

Question

Knowing the frequency of a sound, how would you determine the velocity of sound in air?

EXPERIMENT 14

To study the production of beats. (REF. SEC. II:24(c)

Apparatus

Two matched tuning-forks on resonance boxes, rubber mallet, wax or plasticine.

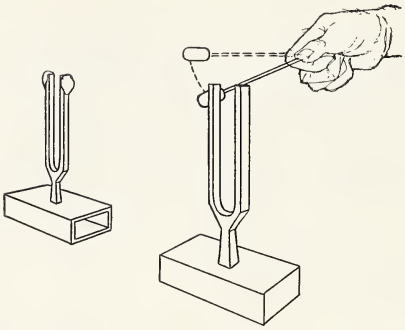


Fig. 10:8

Method

1. Vibrate the two forks together and note the result.
2. Change the frequency of one slightly by putting a little wax or plasticine on its prongs (or rearranging the weights if your forks are of this type) and repeat part 1.
3. Make a still greater difference in the frequencies of the forks (how?) and repeat part 1.

Observations

What do you observe in each part?

Conclusions

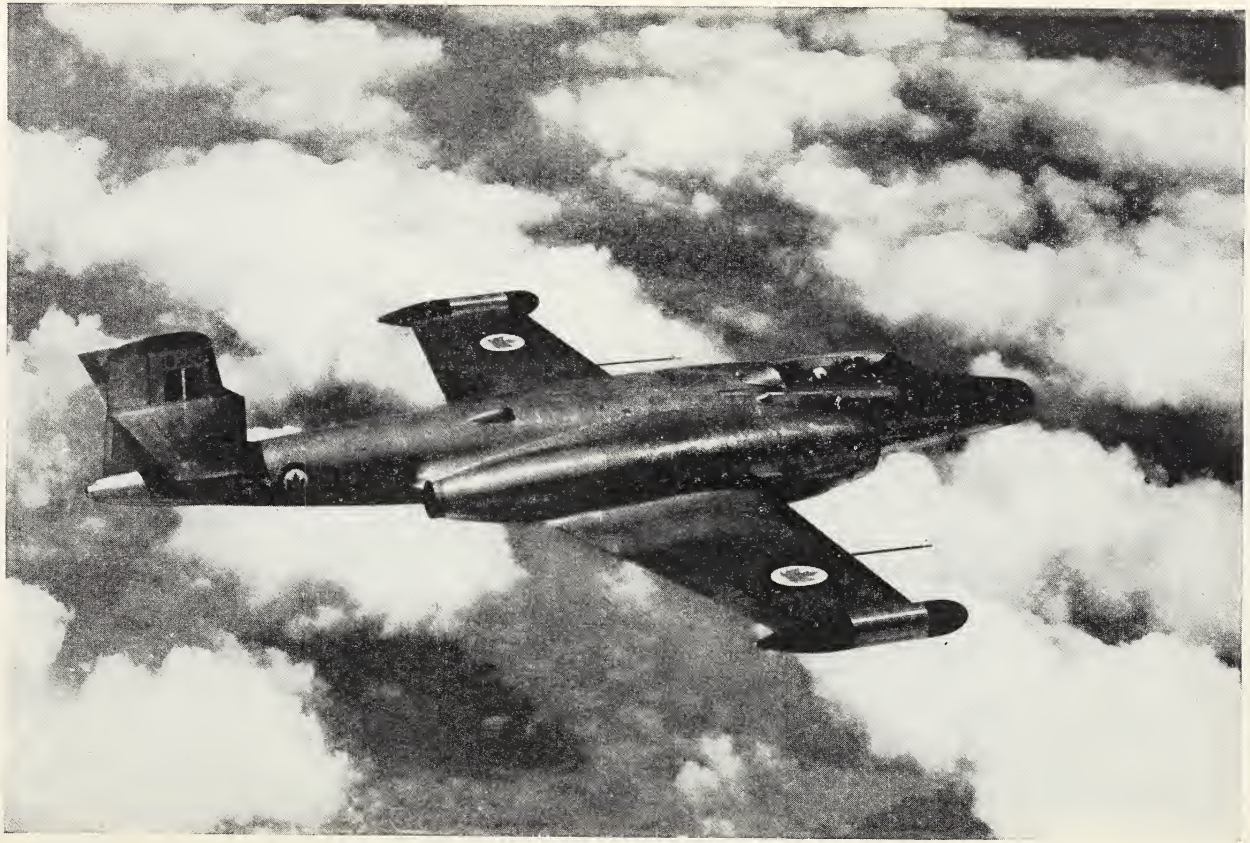
1. How are beats produced?
2. What governs the number of beats per second?
3. Suggest an explanation for beats.

Question

How does a musician use beats to tune his musical instrument?

UNIT III

HEAT



Orenda Engines Ltd.

This Aircraft is Sent Through the Air by Jet-Propulsion. What Heat Effect Plays an Important Role in This?

CHAPTER 11 THE NATURE AND SOURCES OF HEAT

III : 1 HISTORICAL BACKGROUND

Perhaps the greatest single advance made by mankind was the discovery of how to make fire. The presence of ashes and charcoal in caves inhabited in very ancient times, shows that the discovery may have taken place in the Stone Age or earlier. Man's mastery of fire has enabled him to protect himself from exposure to cold, to kill disease-producing organisms and to frighten off wild beasts. It has allowed him to smelt copper and iron from which new weapons and tools could be fashioned. Without this discovery man might not have risen from barbarism.

History reveals the various fire-producing devices used. One was the igniting of dry moss or leaves by heat from the friction between two dry sticks. Another was the production of sparks when a piece of pyrite (fools' gold, a sulphide of iron) was struck a glancing blow with a sharp piece of flint (a hard, compact mass of silica, the mineral of which sand is composed). Both of these are a far cry from the use of such modern devices as matches, electrical igniters etc., although the principle of the flint igniter is still employed in gas and cigarette lighters. The many developments in the production of heat that have occurred since early times give ample evidence of man's creativeness.

Equally interesting are the forward strides made in the understanding of the nature of heat and the laws that govern its use. Not only has man learned how to produce heat but he can now control it, retain it, measure it, transfer it from place to place and convert it into motive power. This study of heat is sufficiently large and important to warrant a special branch of physics, namely, "thermodynamics".

III : 2 THE NATURE OF HEAT

(a) Caloric Theory

Until well into the nineteenth century, most people believed in the Caloric Theory of Heat in spite of questionable proofs to support it. This theory insisted that all empty spaces in matter contained a fluid called caloric and that the warming or cooling of a body was due to the gain or loss in the amount of this fluid. The early Greeks speculated that heat was the rapid vibratory motion of the molecules of a body. Francis Bacon (1561-1626) produced some promising experimental evidence to this effect.

In 1798 an American, Benjamin Thompson, who later became Count Rumford, made further investigations. While directing the boring of cannon, he became interested in the amount of

heat produced in the process and decided to investigate the problem of the nature of heat. The adherents of the caloric theory argued that caloric came out when iron shavings were formed and that the shavings had more of it than the iron. To test this theory, he applied a blunt drill (to produce few shavings) to the cannon with the whole assembly immersed in a box filled with water. In a short time the assembly became warm and finally the water boiled. Because heat was produced as long as the mechanism continued to turn, Rumford concluded that anything which could be produced without limit, as heat had been, could not be a material substance (caloric). He reasoned that heat must be caused by a vibratory motion in the material.

In 1799 Sir Humphrey Davy of England dealt the caloric theory the *coup de grâce* by rubbing together two pieces of ice in a vacuum at a temperature below the melting-point of ice. The caloric theory held that as ice contained no caloric it could not melt under these conditions. But melt it did and in doing so afforded yet more proof that heat must be a product of motion.

(b) The Kinetic Theory of Matter

According to this theory, matter is composed of numerous, tiny, moving particles called molecules, each being separated from its neighbour by empty space. A **molecule** is defined as the smallest particle of a substance which can exist alone and possess the properties of that substance. Scientists are forced to accept such a theory because they know that gases, and to a lesser extent liquids and solids, diffuse, and that gases do not settle but maintain a uniform pressure on the walls of the container. All the evidence indicates that molecules of gases are separated by comparatively vast distances, e.g., water vapour molecules are more than ten times as far apart as water molecules, and possess great freedom of movement. Molecules of liquids have freedom of movement but must be fairly close together, since liquids resist compression. In solids the molecules exhibit great cohesion as illustrated by their rigidity. Their closeness is shown by their resistance to compression. Their movement is said to consist of vibration about certain positions in a prearranged pattern.

(c) Heat—A Form of Energy

Energy is the ability to do work. All moving bodies can do work and therefore have energy. Heat, which is caused by the motion of the molecules of a body, is capable of doing work and therefore must be a form of energy.

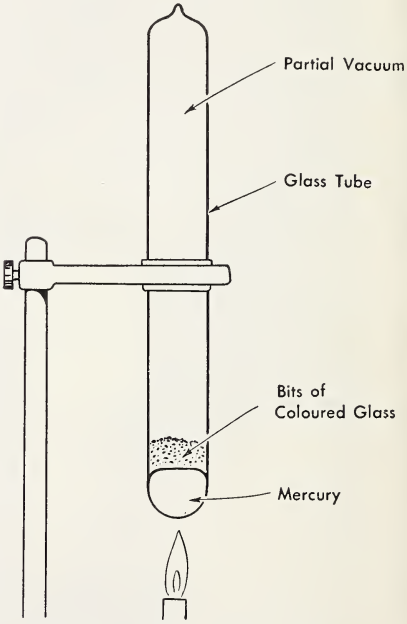


Fig. 11:1 Heat, A Form of Energy.

This may be illustrated with the aid of the apparatus shown in Fig. 11:1. When the tube is heated an effect is observed that imitates somewhat the motion of the molecules. The mercury vaporizes and the molecules of mercury vapour drive the bits of glass upward. The pieces move about erratically, colliding with mercury molecules and each other. Heat is causing the motion of the particles (molecules and glass) and hence heat must be a form of energy. Under other circumstances heat energy may be transformed into other forms of energy such as electricity, light, etc.

III : 3 SOURCES OF HEAT

The origin of heat may be inferred from the **Law of Conservation of Energy.** This fundamental law of nature states that energy can neither be created nor destroyed although it may be transformed into any of its many forms. In practice, if a moving automobile is brought to a stop by its brakes, the energy of motion which disappears changes to heat energy in the brakes. From this and numerous other examples, it is evident that heat is produced at the expense of some other form of energy. A brief discussion of several sources of heat (Fig. 11:2) will follow.

(a) Mechanical Action

In every mechanical operation, the output of work is always somewhat less

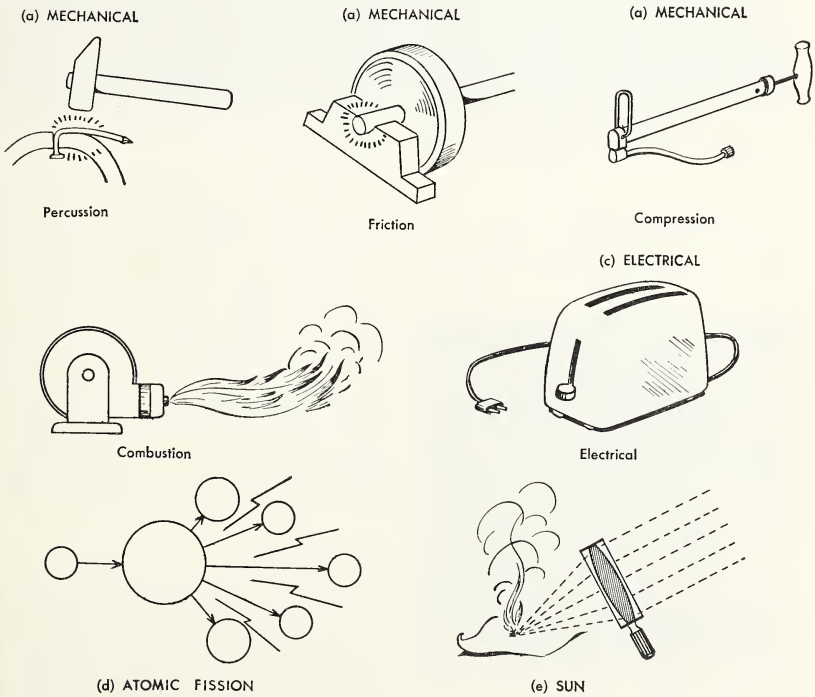


Fig. 11:2 Sources of Heat.

than the input of energy, the loss being equal to the amount of energy converted into heat. This is stated thus:

input = output + heat.

All such operations involve friction, because no surface is perfectly smooth. When one body slides or rolls over another, as when the hands are rubbed together, some of the energy devoted to the purpose is converted to heat.

Frequently, percussion, which is the sudden stopping of a moving object when it collides with one at rest, e.g., hitting a nail, is employed in mechanical operations. Here the energy of motion is converted into molecular motion within both bodies which is manifested as heat.

Some operations involve compression of gases. We know from operating a bicycle pump that some of the energy applied changes into heat. In the Diesel engine (Sec. III:31), the heat produced by compression of the air in the cylinder is sufficient to ignite the fuel.

(b) Chemical Change

When a fuel is burned in air, new materials are formed and energy is released. Such a happening is called a **chemical change**. Every substance has its share of stored chemical energy, a form of potential energy, and when it burns the products of combustion generally possess less of it than do the original materials. The difference in the two energies represents the amount changed into heat. For example:

fuel + oxygen →
carbon dioxide + water + heat.

The total energy of the fuel and of the oxygen equals the total energy of the carbon dioxide and of the water plus the energy which was converted into heat.

(c) The Electric Current

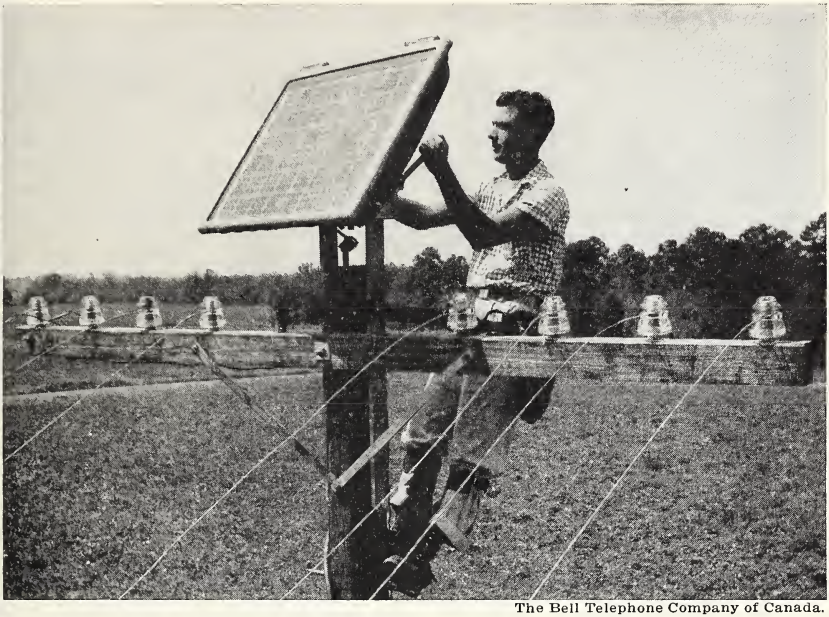
Whenever a conductor carries electricity, it becomes warmer. This is because electrical energy encounters resistance to its flow in much the same way as water encounters resistance (friction) while flowing through a pipe. Just as the moving water loses energy as it overcomes resistance, so too does an electric current. The electrical energy lost becomes transformed into heat. Heating-elements clearly demonstrate this.

(d) The Atom

All matter in the universe is made up from about one hundred different kinds of elements. Elements are simple substances that have not been decomposed by ordinary chemical means. They are composed of atoms which are the building-blocks for the molecules of all substances. Some atoms, like those of uranium or radium, are very large and complex and change into new atoms spontaneously. As they do so a small amount of mass changes into energy some of which becomes heat. There are more details of this process in chap. 32. Huge structures called atomic piles control this energy. Contrary to popular belief, the energy from this source is not limitless but, nevertheless, amazingly large. For example, it has been estimated that one pound of uranium can produce three million times as much energy as one pound of coal or one pint of oil. Imagine how little uranium would be required to heat your home for one year!

(e) The Sun

Few of us realize the importance of the sun as a source of energy. We accept its daily warmth, and take for granted its energy stored in plant and animal products, in the water vapour of the air, in water and air currents, and in the



The Bell Telephone Company of Canada.

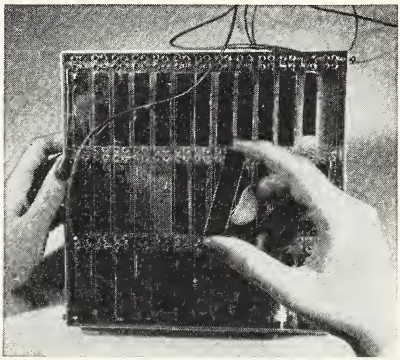
Fig. 11:3 Trapping Solar Energy.

fossil fuels—oil, coal and gas. If the sun were to be suddenly extinguished and all the sources of energy at our disposal were tapped at one time, our accustomed temperature would be maintained for only three days. After that we would quickly freeze to death! In spite of the fact that the earth is only a tiny dot in space, it receives a million-trillion kilowatt hours (Sec. V:75) of energy per year, of which all but .05 per cent slips from our grasp. Green plants trap the major part of this percentage, as follows:

carbon dioxide + water + light energy
(in the presence of chlorophyll)
→ carbohydrates + oxygen

This process is known as photosynthesis.

The sun's internal temperature, estimated at about 20 million degrees centigrade, is maintained by a complicated process which is essentially the union of 4 atoms of hydrogen to form 1 atom of helium gas. Dr. Hans Bethe at



The Bell Telephone Company of Canada.

Fig. 11:4 The Solar Battery.

Cornell University in 1938 showed that there is a decrease in the mass during the process and that this is converted to heat.

For some time man has dreaded a world scarcity of fuel, knowing that at our present rate of consumption we shall be at that critical point in two or three centuries. Accordingly, research workers are constantly seeking ways and means of using solar energy. Some pin their hopes in part on utilizing an improved photosynthetic process, while others are investigating the use of light-sensitive chemicals (Figs. 11:3, 11:4). As the sun will yield its fabulous supply of energy at the present rate for an estimated 10 billion years, our future is assured, provided that inexpensive ways and means of collecting sunlight can be found.

III : 4 QUESTIONS

A

1. (a) Present an argument to show that heat is a form of energy.

   (b) Describe the changes in size and state that occur on intensely heating a piece of iron. Explain each by means of the kinetic theory of matter.

2. Explain each of the following:

   (a) A bullet is found to be warmer after hitting a target.

   (b) Bearings frequently "burn out" when they run short of oil.

   (c) Considerable heat is produced when concentrated sulphuric acid is added to water.

   (d) A fuse burns out in an overloaded electrical circuit.

   (e) The origin of heat from the splitting of the atom.

   (f) The origin of energy from the sun.

3. State all the energy transformations that are involved in the sequence: sunlight, water-power, electricity, heat from a toaster.

4. If the heat from 6 tons of coal will heat a home for one year, what mass of uranium (U235) will do the same thing?

CHAPTER 12 EXPANSION CAUSED BY HEAT

III : 5 EXPANSION OF SOLIDS

Almost all bodies expand on being heated and contract on being cooled. The ball and ring experiment (Chap. 15, Exp. 1), demonstrates the expansion and contraction of metals (Fig. 12:1). That different metals expand and contract by different amounts when heated or cooled through a given change of

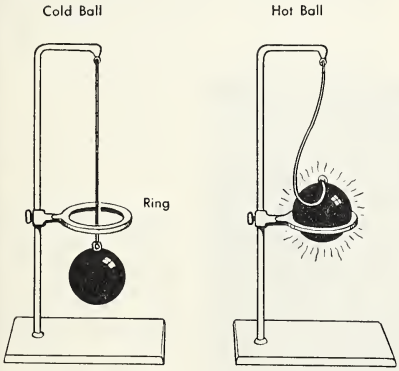


Fig. 12:1 Expansion of Solids.

temperature is shown by the "compound bar" experiment (Chap. 15, Exp. 2). The compound bar or bimetallic strip (Fig. 12:2) consists of equal lengths of iron and brass welded together. On being heated, the bar bends with the

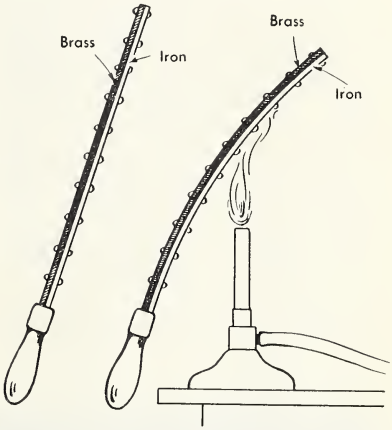


Fig. 12:2 Unequal Expansion of Solids.

brass on the outside. Since the distance round the outside of a curved path is longer than round the inside, the brass has expanded more than the iron for a given change in temperature. On being cooled in a freezing mixture, it bends with the brass on the inside. For this reason, we say that brass contracts more than iron for a given temperature change.

The expansion of metals, though small, exerts great force and is of particular concern to the engineer. For example, rivets are heated before being put into

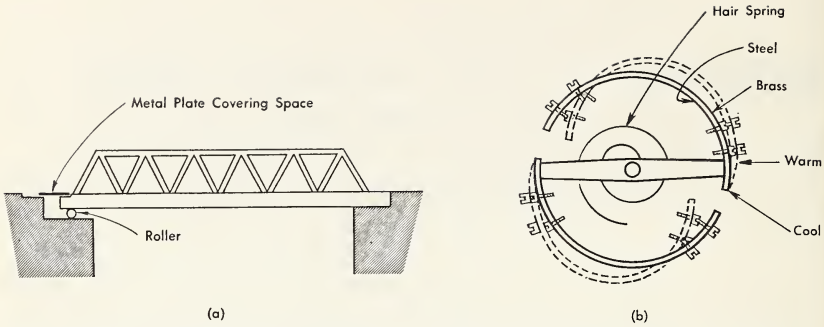
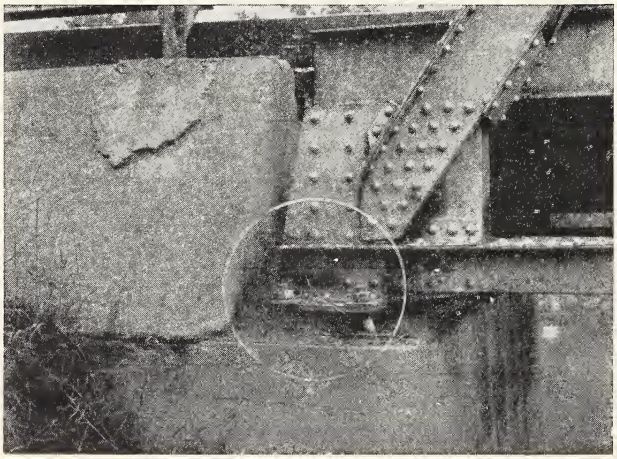


Fig. 12:3 Compensating for Expansion. (a) Bridge (b) Balance Wheel of a Watch.

place so that they will contract and hold the parts securely in place when cool. Steel bridges are subject to considerable contraction and expansion and for this reason are provided with a small gap at the end while the end may rest on a steel roller supported by the abutment (Fig. 12:3a). For similar reasons, there are expansion bends in metal piping, and gaps between the sections of railway tracks; hydro and telephone wires are left slack and a slight clearance is provided between the piston and the cylinder walls of internal combustion engines to avoid "seizing".

To determine the clearances and allowances required, it is necessary to know exactly the small changes in length, area and volume resulting from temperature changes. These can be calculated provided that the appropriate coefficient of expansion is known. Coefficients of expansion are of two kinds, namely, linear and volume. **The linear coefficient of expansion** of a substance is a number representing the increase in length of a unit length of the substance when its temperature is raised one centigrade degree. The volume coefficient may be defined in a similar way. The



Note (Circled) the effect of atmospheric heat on the bolts in the structure of this bridge.

experimental determination of these coefficients is beyond the scope of this course in physics but an explanation of their meaning makes the various applications very much more easily understood.

Coefficients of Linear Expansion of Solids

Substance	*Coefficient*
Aluminum	0.000025
Copper	0.000017
Iron	0.000012
Nickel	0.000013
Platinum	0.0000089
Silver	0.000019
Zinc	0.000026
Brass	0.000019
Invar	0.0000009
Steel	0.000011
Glass (flint)	0.0000088
(soda)	0.0000085
Silica (fused)	0.0000004
Pyrex*	0.0000036

*Pyrex consists of 80 per cent silica and 20 per cent various oxides of metals, chiefly of boron.

III : 6 APPLICATIONS OF EXPANSION OF METALS

Some applications of expansion have been mentioned already and it is clear that the expansion of metals, though small, must always be taken into consideration. The errors in using metal surveying tapes have been largely overcome by the use of invar steel, a nickel-steel alloy containing 36 per cent of nickel and having a coefficient of linear expansion which is almost negligible. The same material is used for the pendulums of clocks to ensure almost constant length and accurate time-keeping.

Watches are controlled by a metal balance-wheel (Fig. 12:3b) and hairspring, the time of oscillation of the wheel being determined by its diameter. A rise in temperature would cause the diameter of the wheel to increase and, consequently, the watch would lose time. To compensate for this defect the rim of the wheel is made in segments, each being a bimetallic strip of brass and steel with the more expansible metal on the outside. When the temperature rises, the segments curl inward, reducing the "effective diameter" of the wheel and compensating for the troublesome increase in diameter that would otherwise occur.

The principle of the bimetallic strip finds other applications. One is the dial thermometer (Fig. 12:4a). The essential part of this instrument is a coiled bimetallic strip, again with the more expansible metal on the outside. One end of the coil is firmly attached to the case of the instrument and the other is connected to the pointer. As the coil winds or unwinds with a rise or fall in temperature, the movement of the free end is transmitted to the pointer moving over a scale graduated in degrees. Although not as accurate as other thermometers to be described in Sec. III:8, it is a robust instrument and has the advantage of containing no liquid to vaporize or solidify. Such a device is also an essential part of the thermograph or

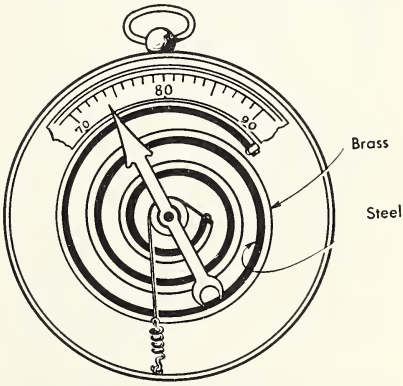
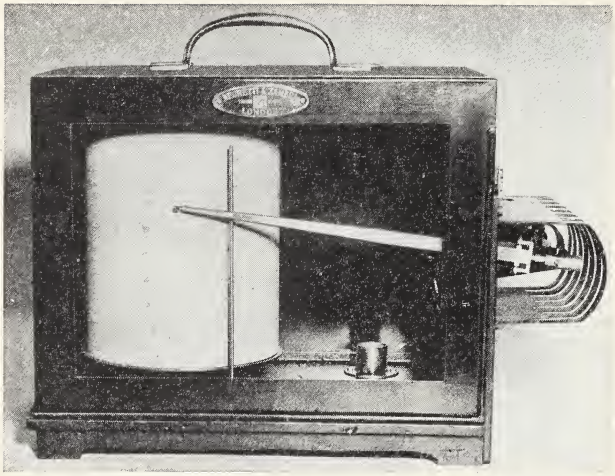


Fig. 12:4 (a) The Dial Thermometer.



(b) The Thermograph.

continuous recording thermometer (Fig. 12:4b).

Thermostats for automatically regulating temperature contain a bimetallic strip as the controlling feature. Such devices are pictured in Fig. 12:5. Fig. 12:6 shows a simple circuit controlled by one. Thermostats control the temperature of ovens, refrigerators, rooms, homes and hot-air furnaces. The par-

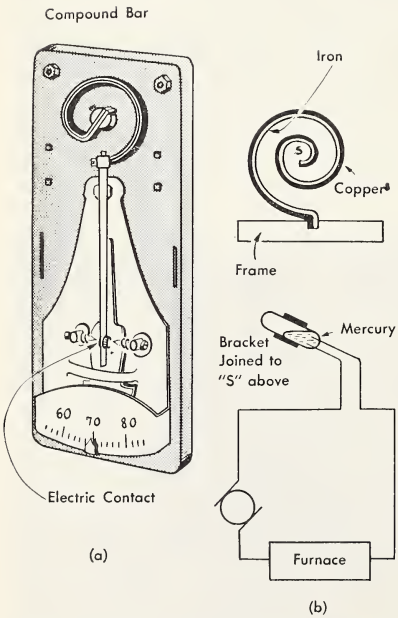


Fig. 12:5 Thermostats (a) Household Type. (b) Type with Mercury Switch.

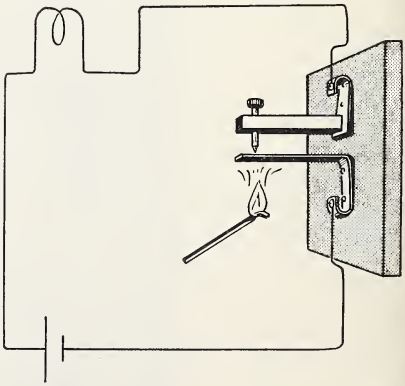


Fig. 12:6 A Simple Thermostat.

ticular type used in hot-water furnaces is called an aquastat. Thermostats may be also used to activate fire-alarms and for a variety of other purposes, where heat is involved. In every case the bending of the metal closes or opens a switch which controls the supply of electricity to the device.

III : 7 EXPANSION OF LIQUIDS

When liquids are heated, they too expand and, when cooled they contract (Fig. 12:7). The actual expansion or contraction is always somewhat greater than that observed because of the expansion and contraction of the container. With suitable apparatus, the expansion in volume per centigrade degree, i.e., the coefficient of expansion in volume, may be determined. Some liquids, like alcohol, show a larger coefficient than others. Most, except mercury, show a different coefficient at different temperatures. The table shows a few of these coefficients including some coefficients of expansion for water at various temperatures. It is this property of a liquid which often determines its suitability for certain purposes, such as in thermometers. Again allowance must be made for expansion wherever liquids are being heated in confined spaces, such as in hot-water heating systems (Sec. III:14).

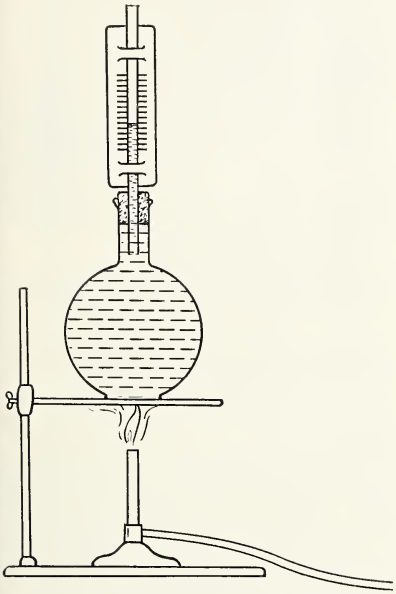


Fig. 12:7 Expansion in Liquids.

Coefficients of Cubical Expansion of Liquids

Liquid	*Coefficient*
Alcohol	0.00110
Glycerine	0.00053
Mercury	0.00018
Water 5-10°C.	0.00005
10-20	0.00015
20-40	0.00030
40-60	0.00046
60-80	0.00059
80-100	0.00070

III : 8 THERMOMETRY

(a) Temperature

If a scale is attached to the long glass tube (Fig. 12:7) while performing the experiment described in Sec. III:7, a form of thermometer registering an increase or decrease in the temperature will be constructed. The **temperature** of a body may be defined as that condition which determines the direction of heat flow between it and its surroundings. Thus, a body at a high temperature will give heat to cooler objects while a body at a low temperature will take in heat from warmer objects. This will proceed until all objects are at the same final temperature.

(b) Thermometers

Originally, man relied solely on his

sense of touch to measure temperature. Obviously, judgments obtained in this way are not very precise. For example, a door-knob feels colder to the touch than the wooden door. Again, if one hand is placed in a beaker of hot water, and the other in a beaker of cold water, and then both hands are placed simultaneously in lukewarm water, the first hand will get the impression of coolness and the second that of warmth. Clearly,

Fig. 12:8 Filling a Mercury Thermometer.

therefore, some means of measuring temperature that is more sensitive and more reliable than that provided by human sensations is needed for scientific purposes. We must have a precise, consistent scale of temperature and an instrument for measuring it accurately. The evolution of the modern thermometer is an interesting story. Students are advised to consult a good encyclopedia for the contributions of such men as Galileo, Viviani, Rey, Boulliau and others who have shared in its perfection.

The modern thermometer is constructed from a length of capillary tubing of uniform bore, sealed at one end by heating it in a flame. By gently blowing down the tube when it is hot, a small bulb is produced at B (Fig. 12:8). This should be very thin if the instrument is to register rapidly. After the tube has cooled, a small funnel is attached to the open end A, and clean dry mercury is poured into it. Before the mercury will fill the bore it is necessary to heat and cool the bulb alternately to force the air past the metal. When the tube is full, it is heated to expel any remaining traces of air. The bulb is now placed in a bath of liquid which has a temperature of 10° to 15° higher than the highest temperature which the thermometer will be required to register. Using the fine blow-pipe flame, the tube is sealed at a point just below the free surface of the mercury. On removing the thermometer from the bath, the mercury contracts in the stem, leaving a vacuum in the space above it.

To graduate the thermometer, we choose two fixed temperatures which can be easily obtained, and mark the level of the mercury on the stem when each of these temperatures has been maintained for some little time. The temperatures chosen are the freezing- and boiling-points of pure water at standard atmospheric pressure (760 m.m. of mercury). The former is called the **lower fixed point** and is marked on the stem by making a groove in the glass with a file at the level of the mercury when it has been standing for some time in melting ice (Fig. 12:9a). To obtain the **upper fixed point**, the thermometer is placed in the apparatus shown in Fig. 12:9b where the bulb and stem are surrounded by steam. When the mercury level is stationary the upper fixed point is scratched on the stem. If the pressure is not standard, it is necessary

to apply a correction before making this mark.

Having determined the positions of the fixed points, we divide the distance

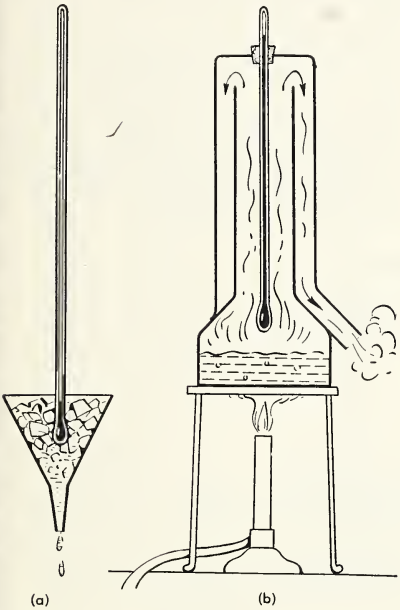


Fig. 12:9 Determining the Fixed Points on a Mercury Thermometer (a) Freezing-point. (b) Boiling-point.

between them into equal divisions or **degrees.** Then we test the thermometer at various temperatures against a standard instrument for accuracy.

(c) Temperature Scales

Two thermometer scales, the **Fahrenheit** and **Centigrade** or **Celsius** are in common use in English-speaking countries. The former is used in everyday practice while the latter is used in science. In countries that are not English-speaking the centigrade thermometer is used for all purposes.

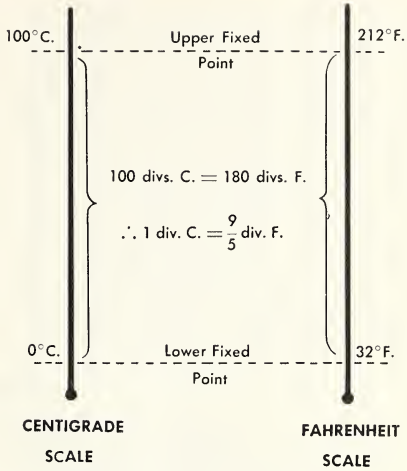


Fig. 12:10 Comparison of Temperature Scales.

Daniel Gabriel Fahrenheit (1686-1736), a German instrument maker at Amsterdam, selected the fixed points 212°F. and 32°F. and constructed the scale that bears his name. In choosing

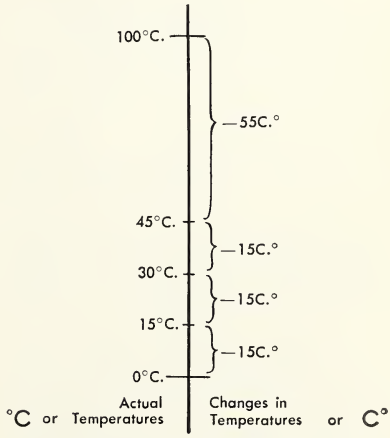


Fig. 12:11 The Comparison of °C and C°.

those fixed points, he was influenced by the incorrect thought that 0°F. was the lowest temperature that could be reached. The centigrade scale introduced by the Swedish scientist Celsius, in 1742, had the fixed points of 100°C. and 0°C. representing, respectively, the boiling- and freezing-points of pure water.

The comparison of these two scales may be seen by reference to Fig. 12:10 and with its help we are able to convert a temperature on one scale to a corresponding temperature on the other. However, before we attempt any conversions it should be stressed that °C. and °F. refer to actual temperatures whereas C.° and F.° refer to a change of temperature anywhere on the scale. For example, the difference between 15°C. and 15C.° is shown in Fig. 12:11.

(d) Conversion of Temperatures

Since both temperature scales are legal, it is important that we be able to convert a centigrade reading into the corresponding Fahrenheit reading, and vice versa. The following examples will show how this is done.

Examples

1. Convert 20°C. to a Fahrenheit reading.
   20°C. is 20C.° above the freezing-point (0°C.)
   100C.° = 180F.°

$$1\text{C.}^\circ = \frac{180}{100} = \frac{9}{5}\text{F.}^\circ$$

$$20\text{C.}^\circ = 20 \times \frac{9}{5} = 36\text{F.}^\circ$$

   ∴ 20°C. is 36F.° above the freezing-point (32°F.)
   ∴ 20°C. = (32 + 36) = 68°F.

2. Convert 14°F. to a centigrade reading.
   14°F. is 18F.° below the freezing-point (32°F.)
   180F.° = 100C.°

$$1\text{F.}^\circ = \frac{100}{180} = \frac{5}{9}\text{C.}^\circ$$

$$18\text{F.}^\circ = 18 \times \frac{5}{9} = 10\text{C.}^\circ$$

   ∴ 14°F. is 10C.° below the freezing-point (0°C.)
   ∴ 14°F. = (0 — 10) = — 10°C.

The above conversions may be accomplished more conveniently by applying the following formula:

$$^\circ\text{C.} = \frac{5}{9}(^\circ\text{F.} - 32)$$

However, it is only by a study of the foregoing examples that the reasons for the various operations in the formula will be understood. Students are advised not to attempt to use the formula until they have mastered the previous solutions.

III : 9 EXPANSION OF GASES

You will remember from your earlier studies of science that gases expand on heating and contract on cooling (Fig. 12:12). In addition, you will recall that gases expand much more than liquids

and solids for a given change of temperature, i.e., they have a greater coefficient of expansion. It may seem

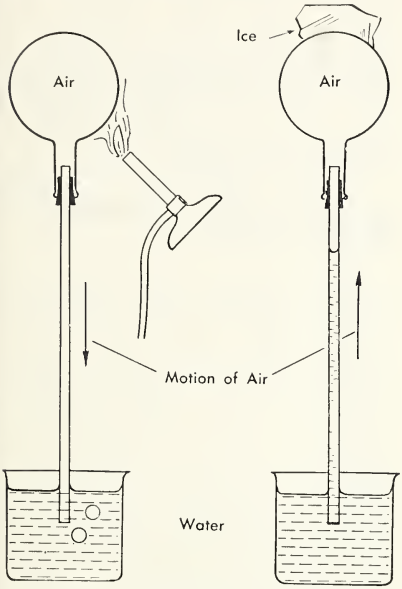


Fig. 12:12 Expansion ond Contraction of Gases.

strange, but is nevertheless true, that all gases have almost exactly the same coefficient of expansion. This may be expressed thus:

"At constant pressure, the volume of a given mass of gas increases by 1/273 of its volume at 0°C. for each centigrade degree rise in temperature".

It should be noted that, because gases are compressible, constant pressure must be prescribed for this relationship to hold.

A special use of the coefficient of expansion of gases is in determining "absolute zero". If we were provided with a tube containing 273 c.c. of gas at 0°C. it would contain 263 c.c. at —10°C., 200 c.c. at —73°C., and theoretically, 0 c.c. at —273°C. We know, of course, that we cannot destroy matter in this way and that the gas would have changed in state before reaching this temperature. This temperature, —273°C., is called **absolute zero**, a temperature at which bodies possess no heat whatever, all molecular motion having ceased. More accurately, absolute zero is —273.16°C. The lowest temperature so far recorded is .005° above absolute zero.

Absolute zero is the lowest point on another temperature scale, **the Absolute** or **Kelvin Temperature Scale**, first proposed by Lord Kelvin, a great English scientist (1824-1907). This finds application in the calculation of the volumes of gases and will be used extensively for that purpose in your chemistry course. Fig. 12:13 shows the relationship between centigrade and Kelvin tempera-

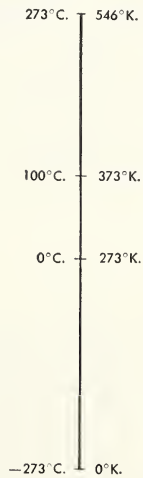


Fig. 12:13 Comparison of Centigrade and Kelvin Scales.

tures. You will see that to obtain a Kelvin temperture 273 is added to the centigrade reading.

A practical application of the effect of heat on the volume of a gas is shown

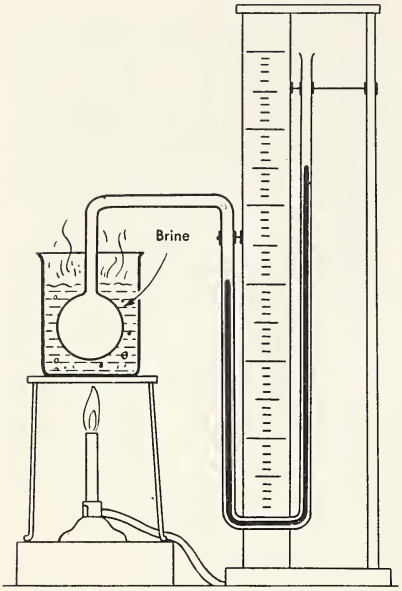


Fig. 12:14 Gas Thermometer.

in the gas thermometer. Instead of allowing the gas to escape as in Fig. 12:12, the instrument is sealed so that the gas is maintained at constant volume and a rise in temperature causes a proportionate rise in the pressure (Fig. 12:14). This pressure change is read directly in degrees. For low temperature work hydrogen or helium is used. Above 500°C. they would diffuse through the bulb and for this reason nitrogen is used instead. This device is used to calibrate thermometers.

III : 10 THE EFFECT OF EXPANSION ON DENSITY

Since changes in temperature cause changes in volume without affecting the mass, densities of substances vary with the temperature. When heat is applied, substances usually expand and a decrease in density occurs. Substances are said to be "lighter" then. The opposite effect occurs when they are cooled. A few exceptions to this rule are known, the most outstanding being water. As was shown in Sec. I:6, water contracts when its temperature rises from 0°C. to 4°C. and thus its density increases. This is known as the anomalous behaviour of water. Above and below these temperatures water behaves normally.

III : 11 QUESTIONS

A

1. (a) A threaded metal cover on a glass sealer fits too tightly. How may it be released? Explain your method.
   (b) What error would be introduced into a measurement by using a surveyor's tape made of copper? What material is used to avoid such errors? Why?
2. (a) Describe and explain what happens when a bimetallic strip is heated and then cooled.
   (b) What is the purpose of the balance-wheel of a watch? How does it accomplish its purpose?
3. (a) How is a centigrade thermometer scale calibrated?
   (b) Under what conditions is mercury preferable to alcohol as the liquid in a thermometer? Give reasons for your answers.
4. (a) When would gases be used in thermometers? Where and when are such thermometers used?
   (b) What is absolute zero?
5. (a) Define linear and cubical coefficients of expansion.

(b) Why does increasing the temperature usually cause a decrease in the density of a substance?

B

1. Find the readings on the Fahrenheit thermometer corresponding to15°C., 200° C., −60°C., −273°C.

2. Find the readings on the centigrade scale when the Fahrenheit thermometer reads: 100°, 350°, −220°, −50°.

3. (a) At what temperature are the Fahrenheit and centigrade readings the same?

(b) At what temperature is the Fahrenheit reading double the centigrade reading?

4. (a) (i) Express 57°C., −23°C. as Kelvin temperatures.

(ii) Convert 298°K., 237°K. to centigrade temperatures.

(b) (i) Express 98°F., 0°F. as Kelvin temperatures.

(ii) Convert 373°K., 0°K. to Fahrenheit temperatures.

CHAPTER 13 TRANSFER OF HEAT

III : 12 HOW HEAT IS DISTRIBUTED

In a previous chapter we studied the sources of heat energy. Here we shall learn how heat is conveyed from the source so that it may be made to go where it is required, or prevented from going where it is not needed. When a saucepan touches a hot stove it becomes warm: heat has travelled by **conduction.** The current of warm air above a hot radiator is carried upwards by **convection.** A fire-place sends out heat by **radiation.** Thus, the three methods of heat transfer are: conduction, convection and radiation.

III : 13 CONDUCTION

(a) Solids

If one end of an iron bar is placed in a fire, the other end will soon become warm. The heat energy has been transferred along the bar by the process of **conduction.** The rate of vibration of the molecules at the hot end, and therefore their energy, has been greatly increased, and this results in the molecules in successive sections of the bar acquiring increased energy by the chain of collisions that results. In this manner heat is transmitted from molecule to molecule along the length of the bar until the far end becomes hot.

Metals are generally good conductors of heat, some better than others. The differences in the conductivities of four different metals may be shown by performing experiment 3, chapter 15, using a conductometer similar to that shown in Fig. 13:1. The relative conductivi-

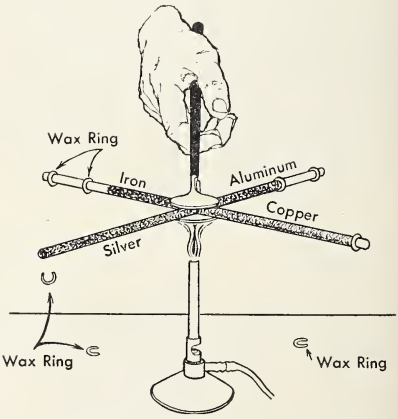


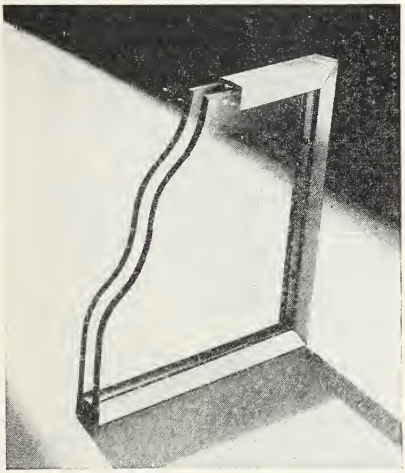
Fig. 13:1 The Conductometer.

ties of some common metals are shown in the table. (The figures used in the table indicate the number of heat units, calories, conducted in one second by a cube 1 cm. to the edge for each centigrade degree.)

CONDUCTIVITIES OF SOME COMMON SUBSTANCES

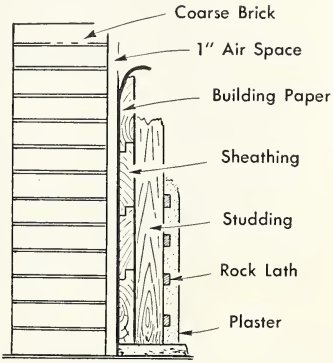
(a) Metals	
Silver	.97
Copper	.92
Aluminum	.50
Brass	.26
Iron	.16
German Silver	.10
(b) Other Solids	
Porcelain	.0025
Glass	.0020
Cork	.0001
Sawdust	.0001
(c) Liquids	
Mercury	.0148
Water	.00139
Alcohol	.000423
Petroleum Oil	.000355
(d) Gases	
Air	.0000568

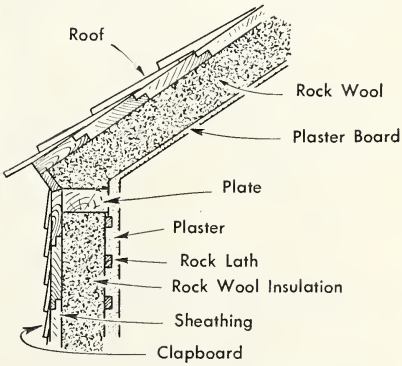
Metals are used for many purposes because they transfer heat efficiently. Boilers, hot-water tanks, cooking utensils and radiators frequently employ copper because of its superior conductivity and durability. However, aluminum may be used because it is lighter, cheaper and more easily shaped. Iron, though heavier



Canadian Pittsburgh Industries Ltd.

One Kind of Window Construction.





Two Kinds of Wall Construction

Fig. 13:2 Methods of Reducing Heat Loss.

and not as conductive as the others, is used for boilers because it can withstand the forces of high pressure better than the other metals.

Certain other solid substances, such as china, plastic material, wood, bone, etc., are employed for their low conductivity, i.e., their inability to pass heat from molecule to molecule readily. These substances are known as insulators. Further examples are cork used in the walls of refrigerators, rock wool, used in outer walls of homes and the wrapping of water tanks, wool for clothing and bedding, glass and porcelain food containers, sawdust in ice-houses, and many others. Some of these, because of the looseness of their texture, contain air pockets which contribute immeasurably to their insulating properties, air being a most efficient insulator.

(b) Liquids

When a test-tube full of water or other liquid is held at the bottom while the top is heated by a Bunsen burner (Fig. 13:3), it is noted that while the bottom remains cold the liquid above

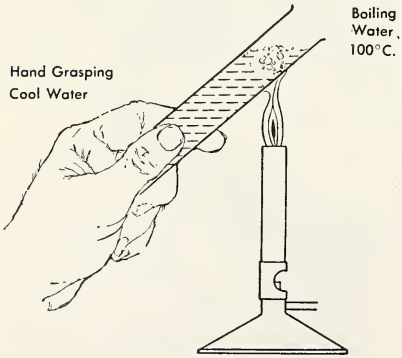


Fig. 13:3 Poor Conductivity of Liquids.

may be boiling. This indicates that liquids are poor conductors of heat. If the positions of the hand and burner are reversed, heat will be transferred quickly from bottom to top, but by convection currents (Sec. III:14), not by conduction. To avoid confusion, it should be stressed that the rule about the poor conductivity of liquids does not include mercury, which, being a metal, is a good conductor.

(c) Gases

If the hand is held close to a Bunsen-burner flame, the resulting burn is not as intense as when gripping a metal bar at the same distance from the flame. This demonstrates that air (or any gas) is a poor conductor of heat. When we recall that gases are composed of molecules that are very far apart and that heat conductivity depends on the actual contact between molecules, we understand why gases are poor conductors of heat.

The above fact concerning gases has many practical applications. In part (a) of this section, reference was made to certain solid insulating materials with loose texture. Many of these, such as fur, wool, sawdust, rock wool, asbestos, snow, etc., depend on the poor conductivity of pockets of air trapped in them for a large part of their insulating properties. Storm-windows, thermopane and the hollow construction of the outer walls of buildings (Fig. 13:2) likewise have insulating value because of the poor heat conductivity of the enclosed air.

III : 14 CONVECTION

(a) Liquids

If a small crystal of potassium permanganate is dropped into a beaker of cold water heated gently by a Bunsen burner (Chap. 15, Exp. 4A), red streaks will be observed as the crystal dissolves (Fig. 13:4). The streaks will rise, move just under the surface of the water for some distance, and fall. Some of the colour may be seen to return to

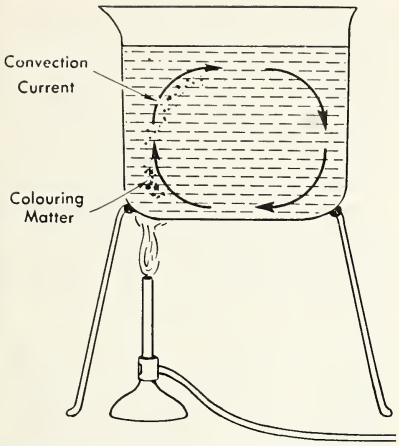


Fig. 13:4 Convection Currents in Liquids.

its point of origin. If we realize that different parts of the liquid in the beaker have different temperatures, then the streaming of the colour signifies that there are rising and falling currents in the water caused by these differences in temperature. These currents are known as **convection currents** and are the means by which the heat is circulated through water and liquids. The movement is established because of the expansion and consequent decrease in density of the water immediately above the source of heat. The mass of hot water is being pushed up continually and replaced by the surrounding denser water. Convection, then, is the transfer of heat in a substance by the actual, sometimes observable, motion of its parts. It should

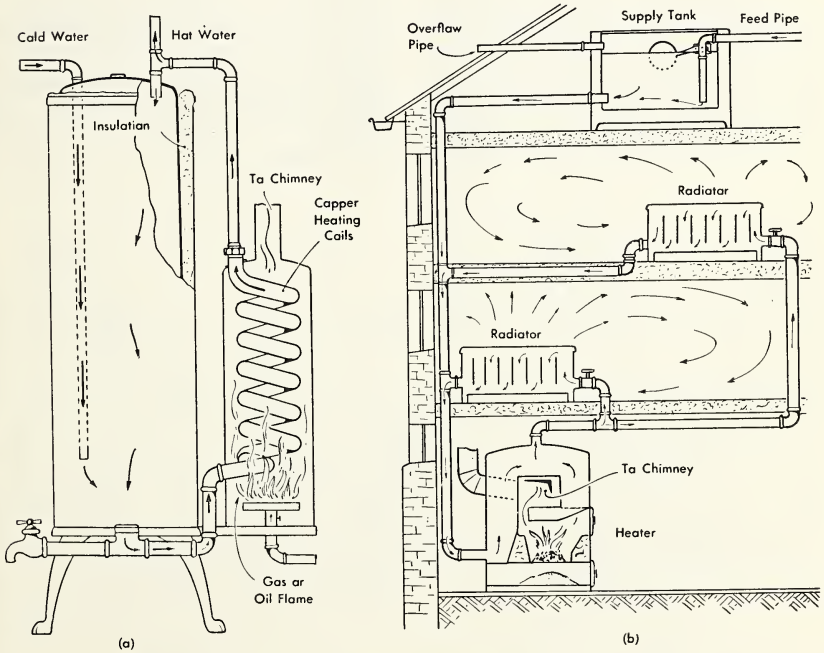


Fig. 13:5 Applications of Convection Currents in Liquids.
(a) Domestic Hot-water Supply (b) Hot-water Heating

be clear from the nature of solids, in which the molecules occupy certain fixed positions, that convection is impossible, but it is possible in liquids and gases where the molecules have greater freedom of movement.

The applications of convection currents in liquids are numerous but only a few will be mentioned. In nature, ocean drifts, which are produced by differences in the temperature of seawater, are an interesting example. The Gulf Stream is a well-known illustration. Others, such as domestic hot-water supply and hot-water heating are presented diagrammatically above (Fig. 13:5). Students should study these and explain how each operates.

(b) Gases

If a glass tube of large diameter is lowered over a burning candle (Fig. 13:6a), the flame will burn fitfully and then go out unless an air inlet is provided at the bottom. If some burning smoke-paper (blotting-paper soaked in concentrated potassium nitrate solution and dried) is held close to the bottom, the smoke will move into the tube and upward. It is evident that the cool, dense air is forcing the heated, less dense air upward. This movement of the air caused by a difference in the temperatures of its various parts and the resulting difference in densities is called **a convection current.** All gases show this phenomenon. The apparatus used to illustrate convection currents in gases is quite varied. Fig. 13:6b shows the form used in Exp. 4B, Chap. 15.

The applications of convection currents in gases (air) are commonplace and not too intricate for the student to explain. A partial list includes ventilation, draught in a chimney, circulation of air in a refrigerator, hot-air heating and winds.

Although all winds are caused by convection currents, we shall confine our attention to land- and sea-breezes (Fig. 13:7). During the day, the land warms faster than the adjoining water. In consequence, the air above the land will be hotter than that above the water

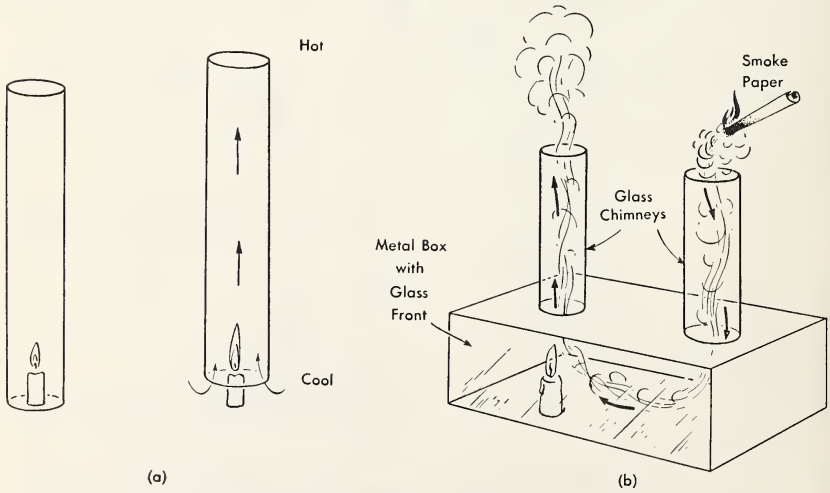


Fig. 13:6 Convection Currents in Gases.

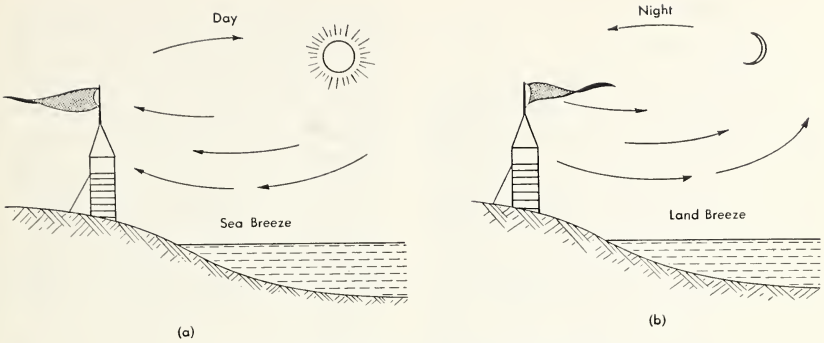


Fig. 13:7 On-shore and Off-shore Breezes.

and a giant convection current, a sea-breeze (i.e., on-shore) results. Conversely, at night, the land will cool faster by radiation (Sec. III:15) and the reverse situation will result in a land-breeze (i.e., off-shore).

Hot-air heating systems (Fig. 13:8) depend upon convection currents for the transfer of heat. However, both have the disadvantage of unequal distribution of heat on cold windy days, when it is hard to heat the windward side of the building. This situation is largely corrected by the use of "forced-air" heating where a motor-driven fan accomplishes the transfer. This system has the further advantage that the air is "conditioned", that is, dust is filtered out and the humidity is more efficiently controlled.

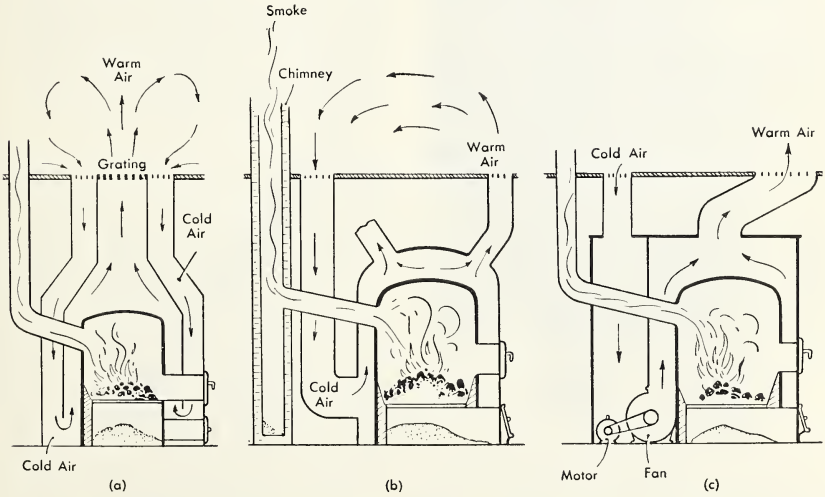


Fig. 13:8 Hot-air Heating (a) Pipeless (b) Conduit Type (c) Forced-air.

III : 15 RADIATION

(a) Introduction

When you stand before a camp-fire, you are aware of its intense heat. Since the effect may be prevented by holding up a blanket between yourself and the fire, you will conclude that the energy travels in straight lines. Since the same thing happens on all sides of the fire, this energy must radiate in all directions, i.e., travel along the radii of a sphere with the fire at the centre. This kind of energy is a form of radiant energy and the method of transfer is called **radiation**. It is only when this energy strikes an object and is absorbed that it changes to heat energy. Transfer of energy by radiation is different from conduction and convection since the latter require a material medium, whereas radiation may proceed through a vacuum. For example, radiant energy from the sun traverses 93×10^6 miles of space, most of which is empty. Or again, energy may radiate from the filament to the glass envelope of an evacuated radio tube.

Radiant energy is a wave-motion and has many properties in common with light. The major heat effect comes from the infra-red radiations just beyond the red of the visible spectrum (Sec. IV:38). Subsequent references to radiant energy in this section refer to these infra-red radiations. All bodies whose temperatures are above absolute zero (Sec. III:9) emit this kind of energy at the expense of the energy of motion of their atoms or molecules. The rate of emission and the wave-length of the radiation is proportional to the temperature: the higher the temperature, the faster the rate and the shorter the wave-length. The waves are believed to be of the transverse variety which, according to one theory, are set up by a minute pulse of energy, called a quantum, from the source. These waves are a part of the great electromagnetic family of waves (Fig. 19:4) that includes visible light, X-rays, ultraviolet rays, radio waves, cosmic rays, etc., all of which have a velocity of 186,000 miles per sec. For their transmission, early physicists invented an imaginary, weightless, all-pervading medium called ether, but the Theory of Relativity proposed by Einstein denies its existence. The nature of the medium still remains a mystery.

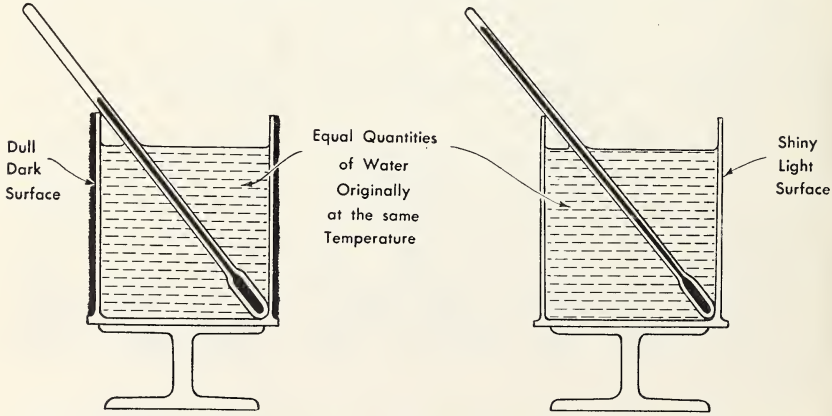


Fig. 13:9 Comparing the Emission of Radiant Energy from Dull Dark and Shiny Light Surfaces.

(b) The Emission of Radiant Energy

In the introduction to this section, it was stated that radiant energy is released at the expense of motion of the molecules. It may well be asked whether or not all objects under the same conditions emit this form of energy. To find the answer, experiment 5, chapter 15, should be performed.

For the purposes of discussion, let us take two cans (Fig. 13:9), one dark and dull on the outside, the other light and shiny, but identical in other respects.

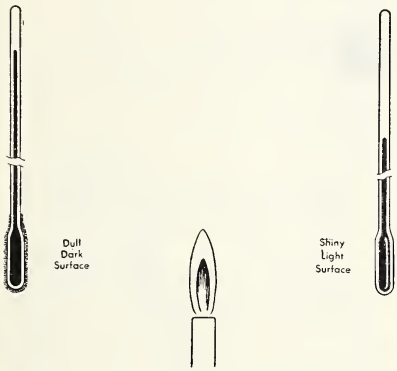
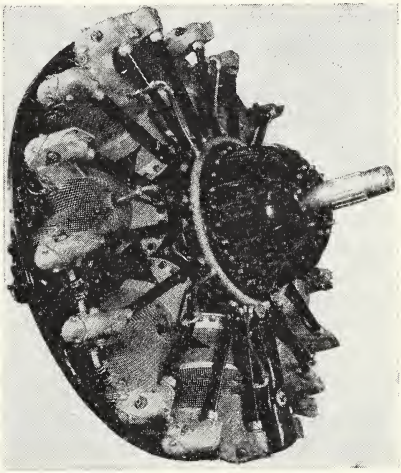


Fig. 13:10 Comparing the Ability of Dull Dark and Shiny Light Surfaces to Absorb Radiant Energy.

Place a quantity of hot water and a thermometer in each and support them on identical insulating-bases. Although both are at the same temperature initially, the water in the dark, dull can cools more quickly than that in the light, shiny one. No matter how we perform such an experiment we always find that **dark, dull surfaces are good emitters of radiant energy, while light, shiny ones are poor in this respect.** It is admitted that other factors, such as starting temperature and area of surface also affect the rate but for the purpose of our discussion, these were kept constant.

(c) The Absorption of Radiant Energy

As was suggested previously, heat results when radiant energy is absorbed. A critical thinker will want to know if different objects absorb this energy equally well. To answer this in part, experiment 6, chapter 15, should be performed. Another demonstration (Fig. 13:10) involves two thermometers, one darkened and dulled by the soot from a candle flame, the other left light and shiny, placed at equal distances on either side of a source of heat such as a Bunsen burner. The temperature of the one with the dark, dull surface rises more quickly than that with the light, shiny surface. We know that dark, dull surfaces absorb light without reflecting much of it and a light, shiny one reflects most of the light without absorbing much of it. In



Can Pratt and Whitney Aircraft.

Radial Engine of Airplane.
Note cooling fins on cylinders.

the same manner **dark, dull surfaces are good absorbers and poor reflectors of radiant energy, while light, shiny sur-**

faces are poor absorbers and good reflectors. Knowing this we wear light-coloured clothes in summer and dark ones in winter.

(d) The Transmission of Radiant Energy

Certain materials are "transparent" or "opaque" toward radiant energy just as some are toward light. As an example, ice does not transmit much radiant energy, while rock salt transmits almost all that falls upon it. Glass, on the other hand, transmits well the shorter wavelengths that originate from a high-temperature source like the sun but does not transmit the longer ones that originate from a low-temperature source such as the earth or a living object. This property of glass makes it useful in greenhouses (part (f) below).

(e) Some Detectors of Radiant Energy

The simplest device is the darkened air-thermometer, or thermoscope, where radiant energy is converted into molecular motion which manifests itself as a rise of temperature (Fig. 13:11a).

The radiometer (Fig. 13:11b) consists of an almost completely evacuated glass bulb in which four light aluminum vanes are mounted so as to turn easily. One side of each vane is blackened while the other is left shiny. When radiant energy falls upon the vanes, the black surfaces become warmer than the others. Accordingly the few air molecules adjacent to the black sides will become heated and will move away from the vanes. The reaction of the vanes causes them to turn about their pivot. The more radiant energy that enters, the faster will the vanes turn. This instrument is very sensitive to small amounts of radiant energy.

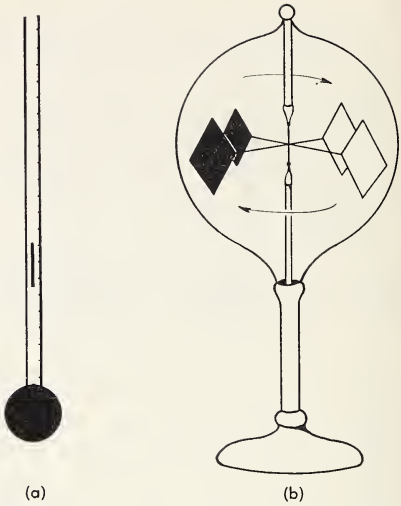


Fig. 13:11 Some Detectors of Radiant Energy. (a) Thermoscope. (b) Radiometer.

(f) Applications of Radiant Energy

The vacuum or thermos bottle (Fig. 13:12) is a double-walled glass bottle, with a high vacuum between the walls, contained in a suitable protective carrying case. The inner glass walls facing each other are silvered. Liquids, whether hot or cold, will remain at very nearly the same temperature for several hours. The reason is that the bottle is so constructed that it is very difficult for heat to be transferred by any of the three methods described above. We shall consider the storing of a hot liquid here. Similar explanations obtain for a cold liquid.

1. The vacuum prevents the loss of heat by conduction owing to the lack of molecules present. The transfer of heat through the glass and the stopper is slow owing to the poor conducting property of each.
2. Convection from inside the bottle

upwards is prevented by the stopper. Loss by convection in the air space between the glass and the case is prevented by being closed at the top.

3. Heat loss by radiation is prevented by the silvered surfaces of the walls. These reflect back into the bottle any radiant energy that tends to escape.

Greenhouses and cold frames (Fig. 13:13) are heated by radiation. The short wave-length radiant-heat energy from the sun is readily transmitted by the glass. This is absorbed by the plants, soil, etc. within; as their temperatures rise, they lose heat by radiation. Since this longer wave-length radiant energy is not transmitted by the glass it is largely reflected back inside. Thus, these devices act as heat traps for the energy from the sun.

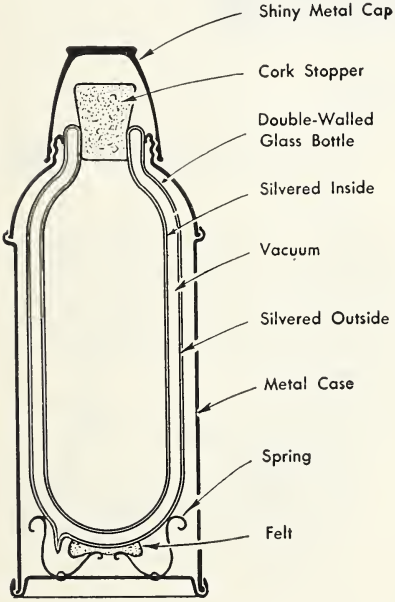


Fig. 13:12 The Thermos Bottle.

A further application, the screening action of the clouds, depends on the inability of water to transmit radiant energy well. The moisture present in the atmosphere absorbs much of the sun's heat by day, thereby preventing the scorching of plant and animal life. At night the clouds provide a blanket which prevents the escape of radiation from the earth's surface, the temperature of which is largely maintained. On the other hand, in hot, dry, arid regions, the absence of water vapour results in extreme temperature changes, being very hot by day and very cold by night.

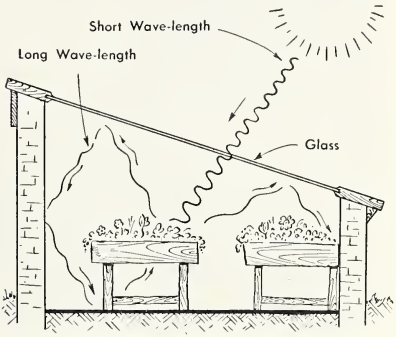


Fig. 13:13 A Greenhouse Acts as a "Heat Trap".

We have included these few applications for their general appeal since they come within the realm of everyone's experience. However, many other applications are to be found both in nature and elsewhere. It is to be hoped that with this introduction to the subject, the student will be able to recognize others as he encounters them.

Installation for radiant heating in a building.

Anaconda American Brass Ltd.

III : 16 QUESTIONS

1. Name three methods of heat transfer and explain how they are involved in heating water in a kettle over an electric heating-coil.

2. (a) On a cold day, why does the metal door handle feel colder than the wooden door? Is it, in fact, colder?
   (b) Name three good conductors and three good insulators of heat, and state the use for each.

3. (a) What are convection currents? Explain how they are produced.
   (b) Explain the production of an onshore breeze.

4. (a) Why does snow melt more rapidly when dirty, than when clean?
   (b) Should the bottom of a kettle be polished for economical heating? Explain.

5. Make a chart comparing conduction, convection and radiation, under the following headings (a) the media in which the transference takes place, (b) direction of the transference, (c) a brief comparison of the theories which explain how the transference occurs.

6. Explain the action of a radiometer.

7. (a) Make a labelled diagram of a thermos bottle.
   (b) Write a note to show how (i) conduction, (ii) convection, (iii) radiation are reduced to a minimum when a hot liquid is placed in the bottle.

CHAPTER 14 MEASUREMENT OF HEAT

III : 17 WHY WE MEASURE HEAT

We know that heat is a form of energy (Sec. III:2c) and that other forms of energy can be changed into heat, but why do we bother to measure it? Were we required to determine the efficiency of an electric heater, the energy yield when a gallon of gasoline, a pound of coal or a tablespoonful of sugar is burned, we should be able to measure the quantities of heat produced. Various fuels and foods are used widely because of their large energy content.

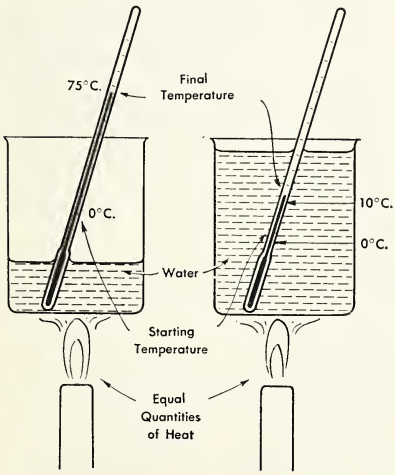


Fig. 14:1 Distinction between Quantity of Heat and Temperature.

III : 18 THE COMPARISON OF QUANTITY OF HEAT AND TEMPERATURE

When two equal masses of water are heated by the same source for the same length of time, each will show the same rise in temperature. If the experiment is repeated with one mass larger than the other (Fig. 14:1), the smaller mass will show a greater rise in temperature. If two unequal masses of water are heated to the same temperature by the same source, the larger mass will require to be heated for a longer time. It is evident that temperature and quantity of heat are entirely different and should never be confused.

III : 19 FACTORS THAT INFLUENCE THE QUANTITY OF HEAT

We are all familiar with the fact that a basin of hot water may be cooled by the addition of cold water and that the final temperature of the mixture will be lower than that of the hot water and higher than that of the cold. We realize that the hot water becomes cool as it gives heat to the cold water while the cold water becomes warm because it gains heat from the hot. This is the principle of heat exchange and it applies whenever substances at different temperatures are mixed (Sec. III:22).

Let us mix two equal masses of water, at different temperatures, each with equal masses of water, at the same temperature. Since the warmer water gives rise to the higher final temperature (see example), the mass at the higher temperature obviously contains the greater quantity of heat. Therefore, **the quantity of heat contained in a body varies as its temperature.** For example:
When 100 gm. of water at 80°C. are added to 100 gm. of water at 20°C., the final temperature is 50°C.
When 100 gm. of water at 40°C. are added to 100 gm. of water at 20°C., the final temperature is 30°C.

Let us mix two different masses of water, at the same temperature, each with equal masses of water, at the same temperature. As the larger mass gives rise to the higher final temperature (see example), it follows that the larger mass contains the larger quantity of heat. Thus, **the quantity of heat contained in a body varies as its mass.** For example:
When 100 gm. of water at 80°C. are added to 100 gm. of water at 20°C., the final temperature is 50°C.
When 200 gm. of water at 80°C. are added to 100 gm. of water at 20°C., the final temperature is 60°C.

So far, we have dealt with quantities of water in the above examples, but what would be the effect of using one different substance along with water? For example, let us mix two equal masses, one of water and one of iron filings, at the same temperature, with two equal masses of water, also at the same temperature. The water will give rise to the higher final temperature (see example), because it contains more heat than the iron. Hence, **the quantity of heat contained in a body depends upon the nature of the material of which it is composed.** For example:
When 100 gm. of water at 80°C. are added to 100 gm. of water at 20°C., the final temperature is 50°C.
When 100 gm. of iron filings at 80°C. are added to 100 gm. of water at 20°C., the final temperature is 26°C.

III : 20 THE UNITS FOR MEASURING THE QUANTITY OF HEAT

Because water is a common substance and its capacity for heat is so great, it is used as a reference material in defining the units for measuring the quantity of heat. In the metric system, the unit of quantity of heat is the calorie. A **calorie** is the quantity of heat gained or lost when the temperature of one gram of water rises or falls one centigrade degree.

Example

How many calories of heat are gained by 100 gms. of water when its temperature rises from 20°C. to 80°C.?

Change in temperature = 80 — 20 = 60C.°

Quantity of heat required to raise the temperature of:

$$\begin{aligned} 1 \text{ gm. of water } 1\text{C.}^\circ &= 1 \text{ cal.} \\ 100 \text{ gm. of water } 1\text{C.}^\circ &= 100 \times 1 \\ &= 100 \text{ cal.} \\ 100 \text{ gm. of water } 60\text{C.}^\circ &= 100 \times 1 \times 60 \\ &= 6000 \text{ cal.} \end{aligned}$$

∴ Quantity of heat gained = 6000 calories.

In the British system, the unit of quantity of heat is the **British Thermal Unit.** One B.T.U. is the quantity of heat gained or lost when the temperature of one pound of water rises or falls one Fahrenheit degree.

Example

How many B.T.U. are lost when 100 pounds of water cool from 170°F. to 100°F.?

The change in temperature = 170 — 100 = 70F.°

Quantity of heat lost by:

1 lb. of water cooling 1F.° = 1 B.T.U.
100 lb. of water cooling 1F.° = 100 × 1 = 100 B.T.U.
100 lb. of water cooling 70F.° = 100 × 1 × 70 = 7000 B.T.U.

∴ Quantity of heat lost = 7000 B.T.U.

Note

1. The calorie used when measuring the energy content of foods and fuels (sometimes called the kilogram calorie), is equivalent to 1000 of the calories above.
2. 1 B.T.U. is equivalent to 252 calories.

III : 21 SPECIFIC HEAT

To find the quantity of heat gained or lost by a substance other than water, we must take into account the nature of the substance as well as its mass and the change in its temperature. The calculation is done by multiplying the mass by the change in temperature by a quantity, related to the nature of the substance, called the specific heat. The **specific heat** of a substance is a number representing the quantity of heat gained or lost by a unit mass of substance when its temperature rises or falls one degree. In the metric system, this is the number of calories of heat gained or lost when the temperature of one gram of the substance rises or falls one centigrade degree. In the British system, it is the number of B.T.U. gained or lost when the temperature of one pound of the substance rises or falls one Fahrenheit degree.

THE SPECIFIC HEATS OF SOME COMMON SUBSTANCES

Substance	*Specific Heat*	*Substance*	*Specific Heat*
Water	1.000	Iron	0.110
Alcohol	0.548	Copper	0.092
Ice	0.500	Silver	0.056
Steam	0.500	Mercury	0.033
Aluminum	0.214	Lead	0.031

Example 1

How much heat is gained by 50 gm. of mercury when its temperature rises from 20°C. to 60°C.?

Solution 1

Change in temperature = 60 — 20 = 40C.°.

Quantity of heat required to raise the temperature of:

1 gm. of mercury 1C.° = .033 cal.
50 gm. of mercury 1C.° = .033 × 50 cal.
50 gm. of mercury 40C.° = .033 × 50 × 40
= 66 cal.

∴ Quantity of heat gained = 66 calories.

Solution 2

Change in temperature = 60 — 20 = 40C.°

Quantity of heat gained = mass × change in temperature × specific heat = 50 × 40 × .033 = 66 cal.

∴ Quantity of heat gained = 66 calories.

Example 2

How much heat is lost by a piece of iron weighing 10 lb. when it cools from 150°F. to 70°F.?

Solution 1

Change in temperature = 150 — 70 = 80F.°

Quantity of heat lost by:

1 lb. of iron in cooling 1F.° = .110 B.T.U.
10 lb. of iron in cooling 1F.° = .110 × 10 B.T.U.
10 lb. of iron in cooling 80F.° = .110 × 10 × 80 = 88 B.T.U.

∴ Quantity of heat lost = 88 B.T.U.

Solution 2

Change in temperature = 150 — 70 = 80F.°

Quantity of heat lost = mass × change in temperature × specific heat
= 10 × 80 × .110
= 88 B.T.U.

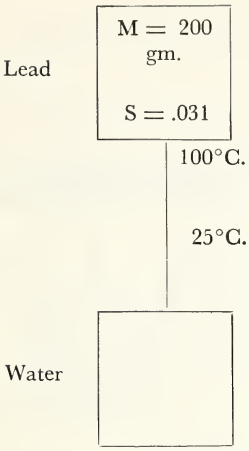
∴ Quantity of heat lost = 88 B.T.U.

III : 22 THE PRINCIPLE OF HEAT EXCHANGE IN MIXTURES

As was explained in Sec. III:19, whenever two substances at different temperatures are mixed or in contact, heat passes from the warm one to the cool one until both have attained the same temperature. Because heat is a form of energy and energy can neither be created nor destroyed (Sec. III:3), it follows that the quantity of heat lost by the warm body equals the quantity of heat gained by the cool one. This is **the principle of heat exchange.**

Example 1

A piece of lead weighing 200 gm. and at a temperature of 100°C. is placed in water and the final temperature of the mixture is 25°C. How much heat is transferred to the water?



Change in temperature $= 100 - 25 = 75$C.°

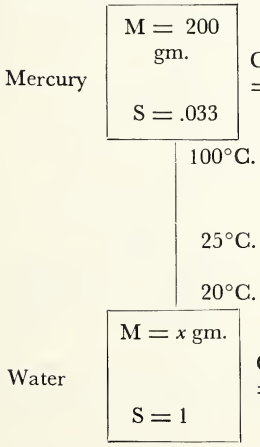
Quantity of heat lost by the lead
= mass × change in temperature × specific heat
$= 200 \times 75 \times .031$
$= 465$ cal.

Heat lost by the lead = gained by the water.

∴ Quantity of heat gained by the water = 465 cal.

Example 2

A mass of 200 gm. of mercury at 100°C. is mixed with an unknown mass of water at 20°C. and the final temperature is 25°C. Find the mass of the water used.



Change in temperature $= 100 - 25 = 75$C.°

Quantity of heat lost by the mercury
= mass × change in temperature × specific heat
$= 200 \times 75 \times .033$
$= 495$ cal.

Change in temperature $= 25 - 20 = 5$C.°

Quantity of heat gained by the water
= mass × change in temperature × specific heat
$= x \times 5 \times 1 = 5x$ cal.

Heat lost by mercury = heat gained by the water

$$495 = 5x$$

$$x = \frac{495}{5} = 99$$

∴ Mass of water used = 99 gm.

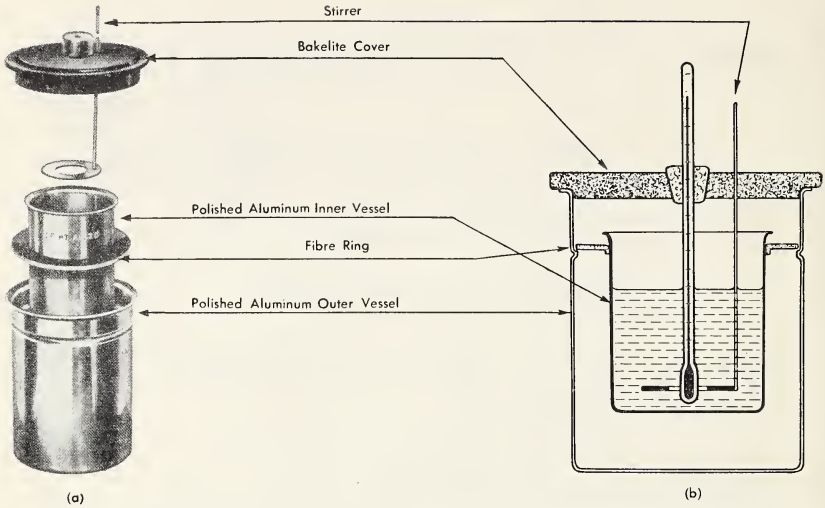


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Fig. 14:2 The Calorimeter.

III : 23 THE CALORIMETER

Students will recognize at once that an operation such as is outlined in example 2 above cannot be conducted without some heat exchange with the surroundings. An instrument called a calorimeter (literally, heat measurer) is designed to prevent as much of this as possible. Its component parts are seen in Fig. 14:2. The small metal can, or inner vessel, of known mass and specific heat is smooth and shiny to avoid radiation of heat from within and absorption from without. It acts as a container during experiments and the heat that it absorbs may be calculated readily. It is supported by a fibre ring which is a poor conductor of heat. The outer metal can is smooth and shiny like the inner vessel to reduce radiation and absorption. The dead air space between the cans reduces loss of heat by conduction. Loss of heat through convection is avoided by the cover. Since it is made of wood, a poor conductor of heat, the cover also prevents loss of heat by conduction. The stirrer, of the

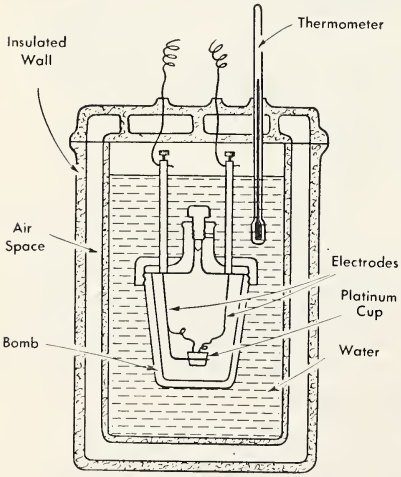


Fig. 14:3 The Bomb Calorimeter.

same material as the inner vessel, is used to permit uniform mixing of the contents.

The materials put into the inner vessel must be so chosen that they do not interact to generate heat. Further, they must not react with the metal. The final temperatures of the materials should not be far above or below room temperature, for best results. If the final temperature is above room temperature, it should be arranged that the initial temperature be the same number of degrees below room temperature and *vice versa.*

An example of a problem involving a a calorimeter follows:

Example

A mass of 200 gm. of mercury at 113°C. is mixed with an unknown mass of water at 18°C. contained in a calorimeter, the inner can and stirrer of which has a mass of 100 gm. and a specific heat of .22. If the final temperature is 23°C., find the mass of the water.

Mercury	M = 200 gm. S = .033	Change in temperature = 113 − 23 = 90C.°	Quantity of heat lost by the mercury = mass × change in temperature × specific heat = 200 × 90 × .033 = 594 cal.
	113°C. 23°C. 18°C.		
Water	M = x gm. S = 1	Change in temperature = 23 − 18 = 5C.°	Quantity of heat gained by the water = mass × change in temperature × specific heat = $x \times 5 \times 1$ = $5x$ cal.
Calorimeter	M = 100 gm. S = .22		Quantity of heat gained by the calorimeter = mass × change in temperature × specific heat = 100 × 5 × .22 = 110 cal.

Heat lost by the mercury = heat gained by the water + heat gained by the calorimeter.

$$594 = 5x + 110$$
$$5x = 594 - 110$$
$$= 484$$
$$x = 96.8$$

∴ Mass of water required = 97 gm.

Another form of calorimeter, the bomb calorimeter (Fig. 14:3) is used in the determination of the energy content of foods and fuels. Some typical results follow:

Calorific Values of Some Common Fuels

Fuel	*B.T.U. per lb.*	*Fuel*	*B.T.U. per cu. ft.*
Gasoline	20,750	Propane	2,450
Fuel Oil	18,500	Acetylene	1,450
Alcohol	11,600	Natural Gas	1,000
Soft Coal	14,000	Coal Gas	300
Hard Coal	11,600		
Wood (average)	5,000		

III : 24 FINDING THE SPECIFIC HEAT OF A METAL

The method generally employed is known as the method of mixtures. The substance whose specific heat is to be determined, say a metal, is mixed with a material which absorbs its heat, say water. From the various observations within the calorimeter the specific heat of the metal can be calculated. A brief summary of the method and a model solution follow. Full details of the method are to be found in experiment 7, chapter 15.

A known mass of copper shot is heated to a known temperature in a water boiler (Fig. 15:5). The metal is transferred to a certain mass of water at a known temperature contained in the inner vessel of a calorimeter. The mass and specific heat of the calorimeter are known. The mixture is stirred until the highest constant temperature is obtained. A table of data and a model calculation follow.

Mass of the calorimeter vessel	= 100 gm.
Mass of the vessel and water	= 200 gm.
Mass of the water = 200 − 100	= 100 gm.
Mass of the copper shot	= 200 gm.
Initial temperature of the copper	= 95°C.
Initial temperature of the water and vessel	= 15°C.
Specific heat of the water	= 1
Specific heat of the calorimeter	= .22
Final temperature of the mixture	= 25.5°C.
Let the specific heat of the copper	= x

Copper	M = 200 gm. S = x	Change in temperature = 95 — 25.5 = 69.5C.°	Quantity of heat lost by the copper = 200 × 69.5 × x = 13900x cal.
	95°C. 25.5°C. 15°C.		
Water	M = 100 gm. S = 1	Change in temperature = 25.5 — 15 = 10.5C.°	Quantity of heat gained by the water = 100 × 10.5 × 1 = 1050 cal.
Calorimeter	M = 100 gm. S = .22		Quantity of heat gained by the calorimeter = 100 × 10.5 × .22 = 231 cal.

Heat lost by the copper = heat gained by the water + heat gained by the calorimeter.

$$13900x = 1050 + 231$$
$$= 1281$$
$$x = \frac{1281}{13900} = .092$$

∴ the specific heat of the copper shot = .092

As in all experiments, some error is unavoidable. Some heat, not accounted for in our method, will be absorbed by other parts of the calorimeter, by the thermometer and a small amount will escape by the methods of heat transfer. With care these losses are quite small.

III : 25 APPLICATIONS OF SPECIFIC HEAT

Specific heats affect our lives more than we realize. Water has the highest specific heat of all common substances (Sec. III:21). Substances with a low specific heat undergo a great rise in temperature when a given quantity of heat is absorbed. When cooled, those same substances undergo a large drop in temperature. On the other hand, water gains or loses a great quantity of heat without much change in temperature.

The high specific heat of water makes it useful in the cooling system of an automobile engine and in hot-water heating. In each case it absorbs large quantities of heat and carries it to a

radiator to be dissipated. Because it has a higher specific heat than land, water does not reach as high a temperature during the summer season or during the day. In the winter season, or at night, water will not cool to as low a temperature as land for the same reason. Thus temperatures over water or near it will always be more moderate than inland. For example the Niagara region has a more moderate climate because of the water round it. The Prairie Provinces, on the other hand, will experience extremes of temperature since there are no moderating influences. The daily differences in temperature referred to above are also responsible for land- and sea-breezes (Sec. III:14) in coastal regions. Agriculturalists know well that wet soils do not warm as rapidly in spring as dry, because of this high specific heat of water. Dry, sandy soils warm up more quickly, produce crops earlier and frequently yield more than one crop in a season.

Metals, as a rule, have low specific heats (Sec. III:21), and this makes them ideal for cooking utensils.

III : 26 HEAT EXCHANGE DURING CHANGES OF STATE

All matter is found in either the solid, liquid or gaseous state. These are the three **physical states of matter.** Each state of matter consists of moving molecules separated from each other by spaces that vary with the state, largest in gases, intermediate in liquids and smallest in solids. The rate of motion of the molecules is faster, and the amount of space between them larger, at higher temperatures. Each state may be converted into one of the others by the addition or removal of heat. In solids and liquids, there is a force of attraction between the molecules known as the **force of cohesion** which must be overcome by the absorption of heat energy before a liquid or gas state may result. Fig. 14:4 shows these changes in state diagrammatically.

The heat exchange during melting (fusion) can be illustrated by stirring some chopped ice or snow with a thermometer while warming it very gently over a low flame. The temperature is 0°C. when we begin and does not rise

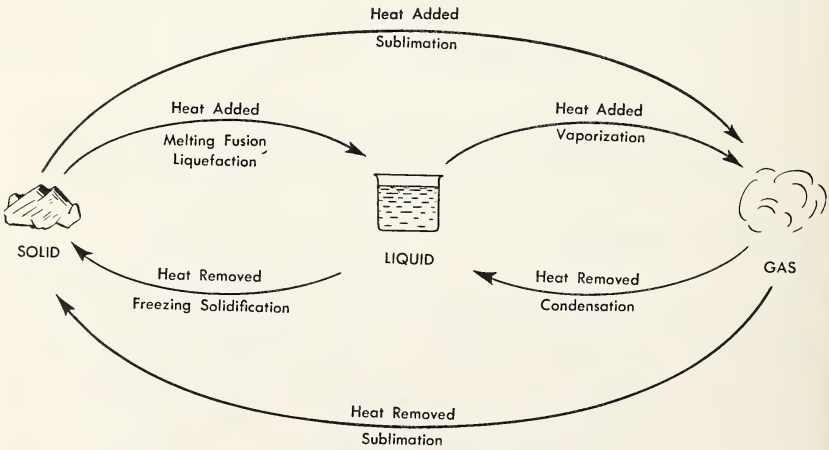
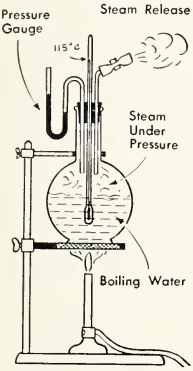
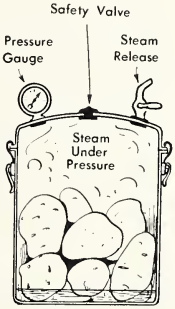


Fig. 14:4 Changes of State.

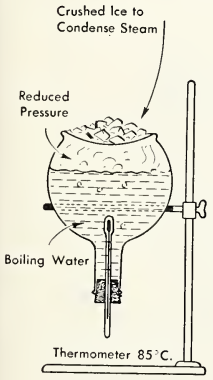
until all the ice has melted. Heat is being absorbed, but, since the temperature does not rise, the heat is being used to melt the ice, that is, to overcome the force of cohesion between the molecules. The temperature at which the solid becomes a liquid is the **melting-point.** Some substances, like ice, sulphur or salt, have a definite melting-point, while others, like glass, wax and tar, melt over a wide range of temperature. We should realize also that freezing occurs at the same temperature as melting and that the same quantity of heat is released during freezing as was absorbed during melting. Moreover, when the temperature of a mass of substance is kept at its freezing-point without any change in the quantity of heat, melting and freezing are both occurring at the same rate, i.e., equilibrium will exist between the ice and the water. It is only when heat is added or removed that one or other process predominates.

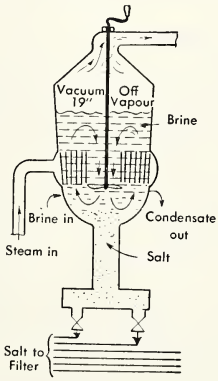
To illustrate heat exchange during boiling, let us heat a quantity of water from 0°C. to 100°C., stirring constantly with a thermometer. It is found that the temperature does not rise above 100°C., although heat is being absorbed continually. The heat is being used to overcome the force of cohesion rather than



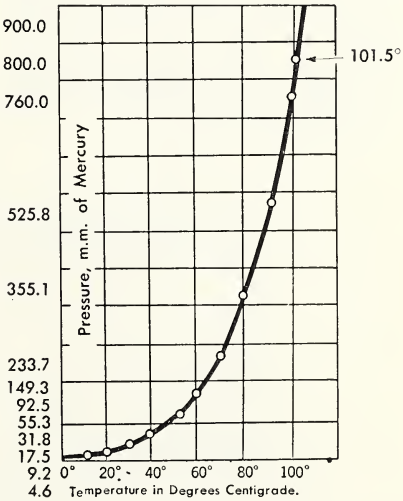


(a) High Pressure Raises Boiling Point. The Pressure Cooker.





(b) Low Pressure Lowers Boiling Point. A Commercial Evaporator.



(c) Graph Relating Pressure and Boiling Point.

Fig. 14:5 The Effect of Changes of Pressure on the Boiling Point of Water.

to raise the temperature. The temperature at which the water is changing from liquid to vapour throughout the whole mass is called the **boiling-point.** Boiling and evaporation are distinguished by the fact that vapour forms throughout the body of the liquid in the former while occurring only at the surface in the latter. Because boiling-points vary with the atmospheric pressure (Fig. 14:5), they are expressed with relation to standard atmospheric pressure (760 mm. of mercury). It should be recognized that the boiling-point is the same as the temperature at which condensation occurs, and the quantity of heat released when a unit mass of vapour condenses is the same as that absorbed during vaporization. Moreover, if the temperature of a mass of liquid is kept at the boiling-point with no change in the quantity of heat, vaporization and condensation take place simultaneously at the same rate, i.e., equilibrium exists between liquid and vapour. It is only when a change in the quantity of heat occurs that either process predominates.

III : 27 DETERMINING THE HEAT OF FUSION OF ICE

In the melting of ice, the quantity of heat required to convert a unit mass of ice to water without a change in temperature is called the heat of fusion of ice. In the metric system, **the heat of fusion of ice** is the quantity of heat in calories required to change one gram of ice at 0°C. to water at 0°C. To determine it, the method of mixtures is employed again. A brief summary of the method, a set of typical results and a sample calculation are presented below but the method in detail will be found in experiment 8, chapter 15.

Small pieces of ice that have been dried with a cloth are allowed to melt with continuous stirring in a known mass of warm water of known temperature, contained in the weighed inner vessel of a calorimeter of known specific heat. When the ice is completely melted, the final temperature is recorded, and, after weighing the vessel and contents, the quantity of ice used may be calculated.

Example

Mass of calorimeter vessel	= 100 gm.
Mass of calorimeter and warm water	= 500 gm.
Mass of calorimeter, warm water and melted ice	= 592 gm.
Mass of warm water = 500 — 100	= 400 gm.
Mass of ice used = 592 — 500	= 92 gm.
Initial temperature of water and vessel	= 32°C.
Final temperature of water and vessel	= 12°C.
Specific heat of the vessel	= .22
Specific heat of water	= 1
Let the heat of fusion of ice	= x

Before we attempt the calculation, let us examine the heat exchange that occurs. Since the water and the vessel cooled they lost heat. This heat did two things. First it melted the ice at 0°C. to water at 0°C. and then it warmed this water to 12°C.

Water	M = 400 gm. S = 1	Change in temperature = 32 − 12 = 20C.°	Quantity of heat lost by the water = 400 × 20 × 1 = 8000 cal.
Calorimeter	M = 100 gm. S = .22		Quantity of heat lost by the calorimeter = 100 × 20 × .22 = 440 cal.
	32°C.		
	12°C.		
	0°C.		
Ice	M = 92 gm. Heat of F = x	No change in temperature	Quantity of heat gained by the ice melting = 92 × x = 92x cal.
Water	M = 92 gm. S = 1	Change in temperature = 12 − 0 = 12C.°	Quantity of heat gained by the ice water warming = 92 × 12 × 1 = 1104 cal.

Heat lost by the water + heat lost by the calorimeter = heat gained by the ice + heat gained by the ice-water.

$$8000 + 440 = 92x + 1104$$
$$92x = 8000 + 440 - 1104$$
$$= 7336$$
$$x = \frac{7336}{92} = 79.7$$

∴ the heat of fusion of ice = 79.7 cal.

There is bound to be a small error in this experiment owing to the use of ice that was not entirely dry and to heat released by the thermometer and other parts of the equipment. With care a fairly accurate result may be obtained. The accepted value for the heat of fusion of ice is 80 calories per gram.

In the British system, the heat of fusion of ice is 144 B.T.U. per pound. It is the quantity of heat required to change a pound of ice at 32°F. to water at 32°F.

SOME TYPICAL HEATS OF FUSION AND MELTING-POINTS

Substance	*M.-P. (°C.)*	*H. of F. (Cal. per gm.)*	*Substance*	*M.-P. (°C.)*	*H. of F. (Cal. per gm.)*
Ice	0	80	Lead	327	6
Aluminum	660	77	Cast Iron	1230	5.5
Copper	1083	42	Mercury	—39	3

III : 28 THE IMPORTANCE OF THE HEAT OF FUSION OF ICE

When one gram of ice melts without a change in temperature, 80 calories of heat are absorbed. This is enough heat to raise the temperature of one gram of water at 20°C. to the boiling-point, or of 80 grams of water through one centigrade degree. Since such a large quantity of heat is required to melt ice, it is not difficult to understand why ice is useful in preserving food.

There are important consequences of this large heat of fusion in nature. Icebergs float long distances before absorbing enough heat to melt. Large snowfalls melt slowly and disastrous floods are avoided. Since ice on lakes and streams melts slowly in spring, sudden extreme changes in temperature do not occur.

On the other hand, the heat released when water freezes is useful. Tubs of water are set near fruits and vegetables in unheated basements when there is a chance of frost damage. As the temperature drops, the water freezes and the heat released prevents the fruits from freezing.

The heat released when lakes and rivers freeze has a moderating effect and prevents extremes of temperature. This helps to make the climate of regions like Southern Ontario milder than regions more distant from large bodies of water. Furthermore, the weather generally becomes milder before or during a snowstorm because of the heat released when the water vapour changes to solid. These examples and many more may be cited to show the usefulness of the heat of fusion of ice.

III : 29 DETERMINING THE HEAT OF VAPORIZATION OF WATER

In boiling water, the quantity of heat required to convert a unit mass of water at its boiling-point to steam without a change in temperature is called the **heat of vaporization of water.** In the metric system, the heat of vaporization is the quantity of heat required to change one gram of water at 100°C. to steam at 100°C. (atmospheric pressure being 760 mm. of mercury). Experiment 9, chapter 15, describes the method used to determine it. A brief summary of the method, some typical results and a set of calculations follow.

The quantity of heat required to vaporize a unit mass of water at its boiling-point is the same as that released when a unit mass of steam condenses. Since the latter is more easily determined, the method involves using it rather than the former. Hence, steam from a boiler is passed through a steam trap to free it of water (It is now called "dry" or "live" steam). It is then conducted into a quantity of cool water of known mass and temperature contained in the weighed inner vessel of a calorimeter of known specific heat (Fig. 14:6). The water is continually stirred and, shortly, the final temperature is recorded. The vessel and contents are weighed to find out the weight of steam used.

Mass of inner vessel of calorimeter		= 100 gm.
Mass of vessel and cool water		= 500 gm.
Mass of vessel, water and condensed steam		= 521.7 gm.
Mass of cool water	= 500 — 100	= 400 gm.
Mass of steam	= 521.7 — 500	= 21.7 gm.
Initial temperature of water and vessel		= 5°C.
Final temperature		= 36°C.
Specific heat of the vessel		= .22
Specific heat of water		= 1
Let the heat of vaporization of water		= x

Let us analyse these results before proceeding. The heat absorbed by the water and the vessel originated not only from the condensation of the steam, but also from the cooling of the resulting water from 100°C. to 36°C. We must recognize these two sources of heat in our calculations.

Steam	M = 21.7 gm. H of V = x	No change in temperature	Quantity of heat lost by the steam condensing = 21.7 × x = 21.7x cal.
Water formed by condensation	M = 21.7 gm. S = 1	Change in temperature = 100 — 36 = 64C.°	Quantity of heat lost by the resulting water cooling = 21.7 × 64 × 1 = 1389 cal.
	100°C.		
	36°C.		
	5°C.		
Cool Water	M = 400 gm. S = 1		Quantity of heat gained by the cool water = 400 × 31 × 1 = 12400 cal.
		Change in temperature = 36 — 5 = 31C.°	
Calorimeter	M = 100 gm. S = .22		Quantity of heat gained by the calorimeter = 100 × 31 × .22 = 682 cal.

The heat lost by the steam + heat lost by the resulting water = the heat gained by the cool water + heat gained by the calorimeter.

$$21.7x + 1389 = 12400 + 682$$
$$21.7x = 12400 + 682 - 1389$$
$$= 11693$$
$$x = \frac{11693}{21.7} = 538.8$$

∴ the calculated heat of vaporization of water is 539 calories. The accepted value is 540 calories.

In the British system, the heat of vaporization of water is 972 B.T.U. per pound and is the quantity of heat required to change a pound of water at 212°F. to steam at 212°F.

HEATS OF VAPORIZATION AND BOILING-POINTS OF VARIOUS USEFUL MATERIALS

Substance	*B.-P.* (°*C.*)	*H. of V.* (*Cal. per gm.*)
Water	100	540
Ethyl Alcohol	78	204
Ethyl Ether	35	84
Chloroform	61	59
Ammonia	— 33	327
Methyl Chloride	— 24	102
Sulphur Dioxide	— 10	95
Freon 12	— 30	41

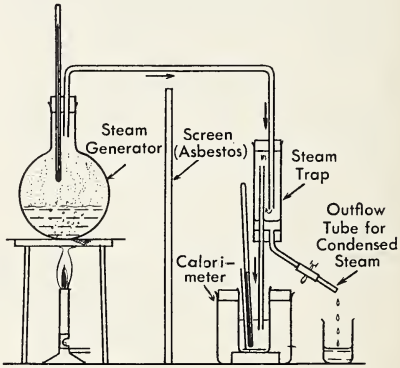


Fig. 14:6 Determining the Heat of Vaporization of Water.

III : 30 APPLICATIONS OF HEAT OF VAPORIZATION

(a) Water

The high heat of vaporization of water is of great practical importance in nature. Evaporation of soil water is slow because of the vast quantity of heat required for this purpose. Thus extremes of drought and torrential rains that would attend excessive evaporation are avoided.

Steam-heating, as used in most large public buildings, is an excellent example of heat of vaporization at work. Water is boiled; the steam is conducted to radiators where it condenses and yields its heat of vaporization. The hot water now flows back to the boiler to be used again. This system is cheaper than hot-water heating (Sec. III:14) as smaller radiators are required and the steam pipe itself often serves as a water return.

Cooling is frequently accomplished by evaporation. The faster-moving molecules of the liquid escape first and the temperature falls. Further evaporation

occurs only if more heat is absorbed from its surroundings. This is the principle involved in the use of perspiration to regulate body temperature, the sprinkling of city streets with water on hot summer evenings, and the alcohol rub to reduce fever.

(b) Refrigerators

The refrigerator makes use of the same principle. The chief requirement is a gas which can be liquefied without difficulty and which has a high heat of vaporization. Some gases of this kind are ammonia, sulphur dioxide, methyl chloride, and—the most widely used—freon 12 (dichlorodifluoromethane).

The parts of a refrigerator are shown in Fig. 14:8. In it, a small electric motor operates a compressor which forces the gas into the coils of a condenser. Here it condenses because of the pressure and cooling (See Faraday's experiment below). A small fan is often provided for cooling purposes, though loss of heat by radiation is frequently sufficient. The liquid proceeds to the cooling-unit where it vaporizes, removing

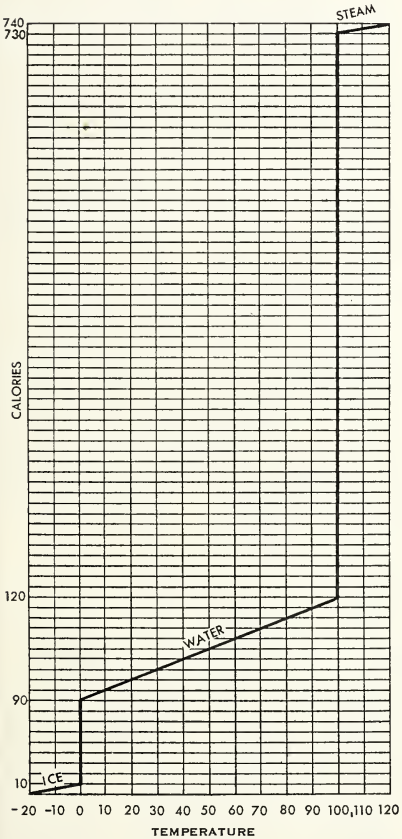
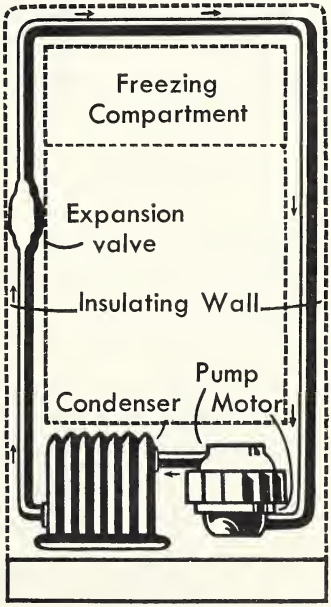


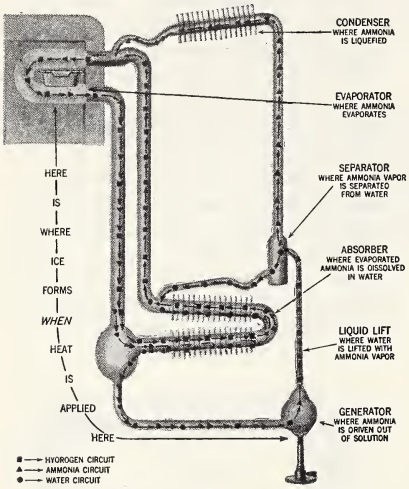
Fig. 14:7 Graph Summarizing Heat Exchanges for the Changes of State of Water.



Frigidaire Products of Canada Ltd.

Fig. 14:8 The Operation of an Electric Refrigerator.

heat from the food compartment. The gas now returns to the compressor to be recirculated. Ice-making machines,



Courtesy of Servel (Canada) Ltd.

Fig. 14:9 The Operation of a Gas Refrigerator.

quick-freeze units etc., all work on the same principle.

The gas refrigerator (Fig. 14:9) involves no moving parts and is, consequently, silent and automatic. The sealed tubes contain water, ammonia and hydrogen. Ammonia, which is ordinarily very soluble, is expelled from the water by the heat of the flame. A combination of the pressure created and the simultaneous cooling by the air causes ammonia to liquefy. It now proceeds to the cooling-unit, evaporates, absorbs heat, redissolves in the water and is ready to repeat the process. Hydrogen is used to prevent the formation of a vacuum which otherwise would be caused by the rapid dissolving of the ammonia. This avoids "pounding". The refrigerator is simple in its principle of operation but its structure is somewhat more complicated than this explanation would lead one to believe.

(c) The Liquefaction of Gases

Michael Faraday, about whom we shall learn more later (Sec. V:57), devised an ingenious method of liquefying gases. He filled a thick-walled glass tube of the type shown in Fig. 14:10 with chlorine gas. One end of the tube was surrounded by a freezing mixture of

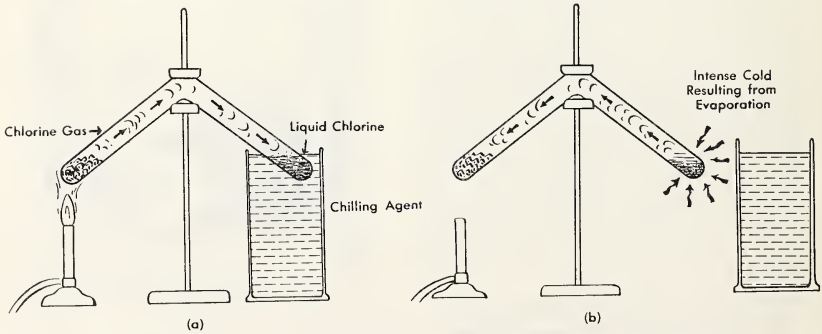


Fig. 14:10 (a) Illustrating Faraday's Method of Liquefying Gases. (b) Producing Cold Artificially.

ice and salt. Heating the gas in the other end caused a rise in pressure while the gas liquefied in the cool end. In this way he was also able to liquefy several other gases. This principle is employed in the gas refrigerator above.

Faraday found that certain gases, for example, oxygen, hydrogen, nitrogen, air and many others, could not be liquefied in this way. It was found that these gases had to be cooled to a certain temperature, called the **critical temperature**, before any amount of pressure would liquefy them. The pressure required to liquefy the gas at this temperature is known as the **critical pressure**.

It should be noted that when the operating temperature is lower than the critical temperature, the pressure required for liquefaction is very much lower than the critical pressure. It is not difficult to understand, then, why the gases sulphur dioxide, ammonia, methyl chloride and freon 12 are said to be easily liquefied at ordinary temperatures.

When a compressed gas is allowed to expand, cooling results. As an example, the air escaping from an inflated

Some Critical Temperatures and Pressures

Substance	*C.T.* (°C.)	*C.P.* (Atm.*)
Sulphur Dioxide	157	78
Chlorine	144	76
Methyl Chloride	143	66
Ammonia	132	112
Freon 12	112	40
Carbon Dioxide	31	73
Oxygen	— 119	50
Air	— 141	37
Nitrogen	— 147	34
Hydrogen	— 240	13
Helium	— 268	2

*One atmosphere pressure = 760 m.m of mercury.

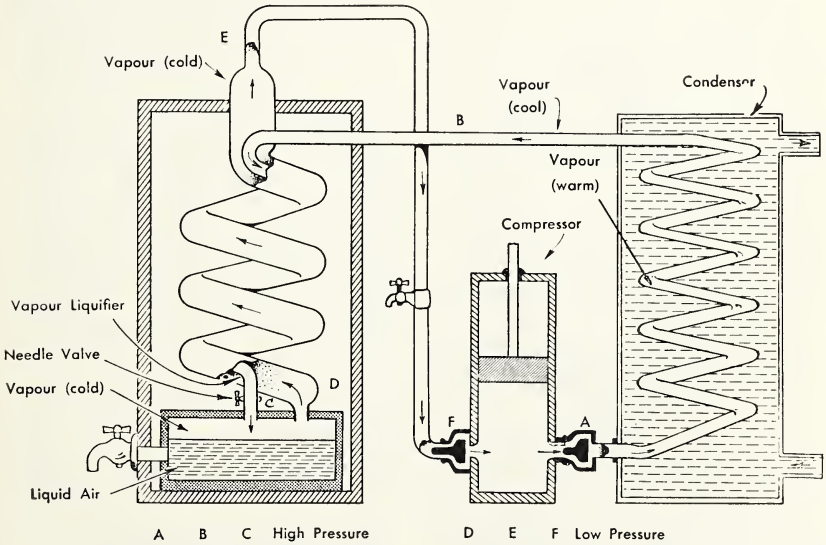


Fig. 14:11 The Production of Liquid Air.

automobile tire feels cold. In liquefying a gas of low critical temperature, the gas is subjected to the cooling effect of an expanding cold gas around it, in order to reach the low temperature required. This principle is seen in operation in the liquefaction of air (Fig. 14:11).

The air is first compressed and then circulated through cooling-coils to remove the heat of compression. It passes on through the needle-valve of the liquefier where it expands, cools, and returns to the compressor by way of a pipe which surrounds the one that carried it to the needle-valve. As these processes are repeated continuously, the gas is soon cooled to its critical temperature and hence it liquefies.

Liquid air at atmospheric pressure boils at between — 182°C. and — 194°C., the variation depending on the percentage of nitrogen present. It is so cold that it will boil when in contact with ice and will convert mercury (F.-P. — 39°C.) into a solid so hard that it can be used as a hammer. It is drawn off into open Dewar flasks of the same construction as "thermos" bottles in which it may be kept for a short time. On standing, the nitrogen will boil off first leaving a pale blue liquid which is largely oxygen.

Liquid air is used in industry as a source for the very low temperature needed for causing metals to contract. It is a source of industrial nitrogen used for preparing nitrogen compounds. From it may be obtained oxygen used for welding, hospitals, aviation etc., together with the inert gases which are used in neon signs, argon bulbs and the like.

Liquid carbon dioxide is prepared in a similar way. When this liquid is allowed to escape from a valve, its evaporation removes heat from the surroundings and from the escaping liquid converting it to "dry" ice. This solid carbon dioxide has a temperature of — 80°C. and changes to a gas without melting (sublimation), hence the apt use of the word "dry". As the heat absorbed in sublimation (87 cal. per gm.) is large and only a small amount of solid is required for a considerable cooling effect, it is used as a refrigerant in shipping. It saves freight and keeps foods at such a low temperature that there is no danger of spoilage. Liquid carbon dioxide is also used for fire-extinguishers.

III : 31 THE RELATIONSHIP BETWEEN HEAT AND WORK

Ancient civilization accomplished work, such as building the Pyramids, by utilizing slave-labour. In recent times various machines have been developed which convert heat into work, so releasing man from much drudgery.

Man has known since the time of Rumford and Davy (Sec. III:2) that work could be converted into heat. Later it was shown that heat can be made to do work. When a pound of coal burns, for example, enough heat (14,500 B.T.U.) is generated to raise a ton of material through 5,000 feet. In practice, only a fraction of the energy from fuel is available to do useful work in an engine because of losses through radiation, conduction, convection, friction etc. The small fraction actually available compared to the total possible amount of energy is called the efficiency. The examples that follow show the efficiency of various kinds of engines.

EFFICIENCIES OF HEAT ENGINES

Locomotives	6-8%
Steam turbine, condensing steam-engine	16-30%
Gasoline (automobiles, aircraft)	22-28%
Diesel (railway, marine, trucks, buses)	32-38%

G.M Corp.

Heat engines are of two types (a) the external combustion engine of which

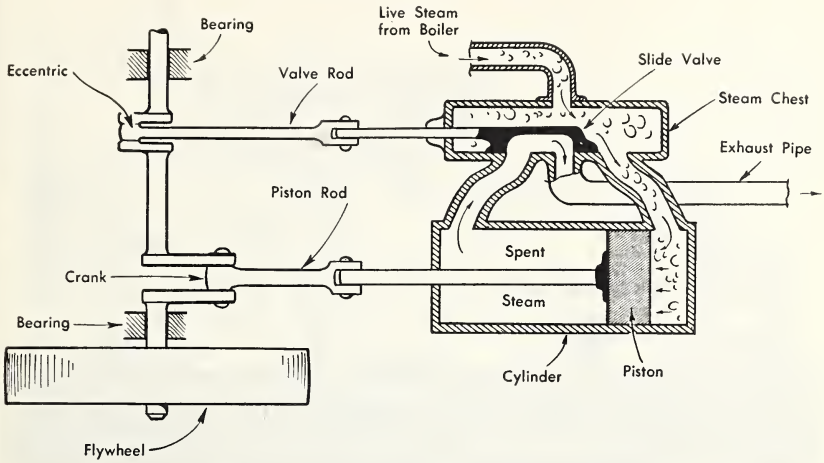


Fig. 14:12 The Reciprocating Steam Engine.

the steam-engine is an example, and (b) the internal-combustion engine as in automobiles and aircraft. In the former the fuel burns outside of the engine proper while in the latter it burns inside the cylinder.

The Steam-Engine

In the common steam- or "reciprocating"-engine, the pressure exerted by live steam (dry and much hotter than 100°C.) pushes the piston back and forth in the cylinder. The back-and-forth motion is made possible by an automatic slide-valve which first admits the steam at one end of the cylinder, thus driving the piston to the opposite end, and then admits the steam at this end, thus forcing the piston back to its original position (Fig. 14:12). This motion rotates the fly-wheel which, being heavy, enables the engine to operate smoothly.

The Steam Turbine

This type of steam-engine is widely used in power-plants and large ships. It consists of a specially designed paddle-wheel against which steam at high pressure is directed through nozzles (Fig. 14:13). The force of the vapour rotates the paddle-wheel. These engines are

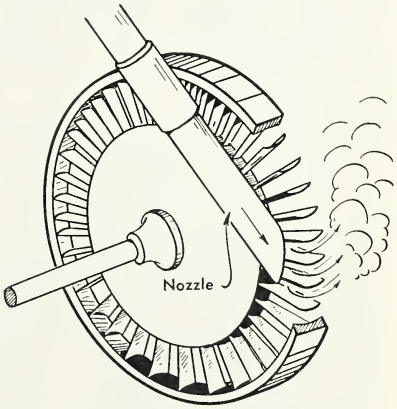
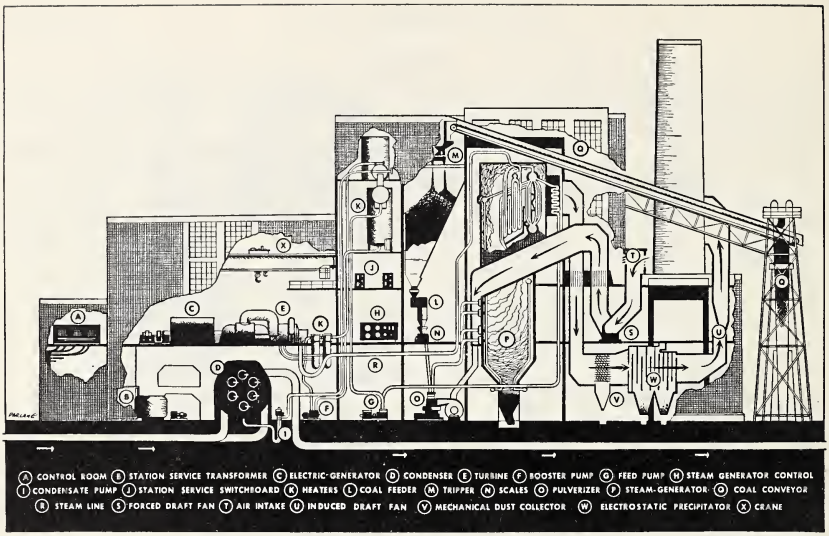
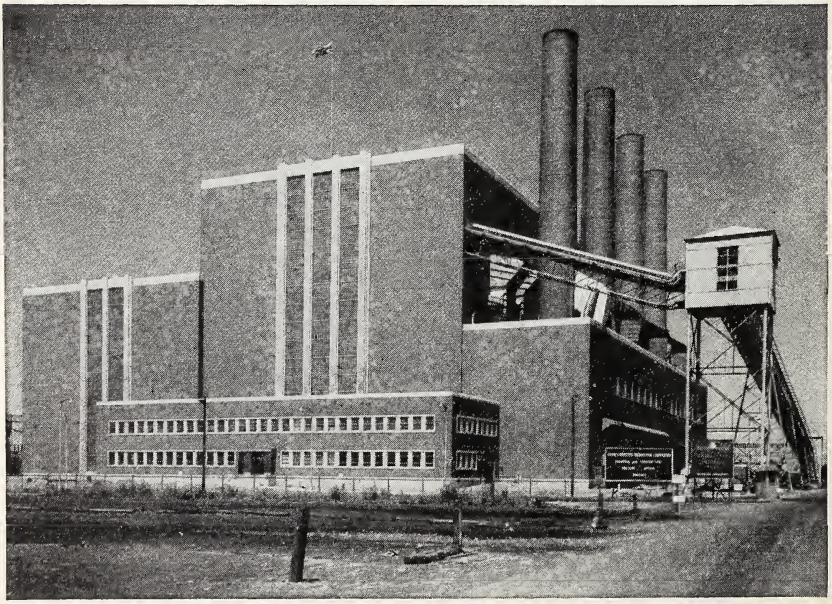


Fig. 14:13 The Steam Turbine.
(a) Principle of the Steam Turbine.



Ontario Hydro

Fig. 14:13 (b) How a Steam Generating Station Works.



Ontario Hydro

Richard L. Hearn Generating Station.

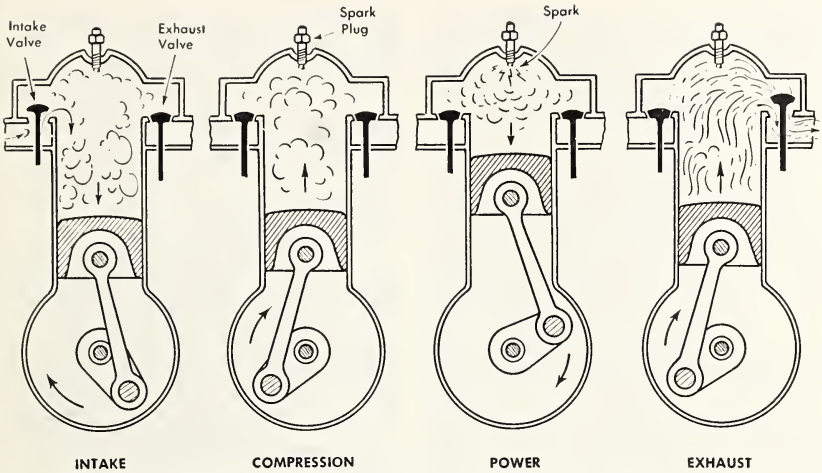
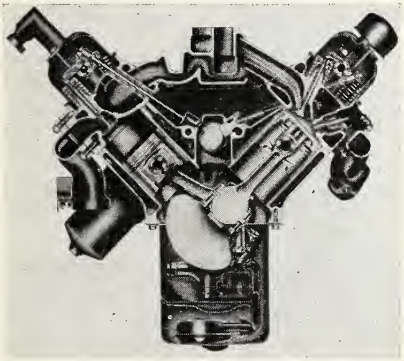


Fig. 14:14 The Four Cycle Internal Combustion Engine. A Sectional View.

designed to use the pressure as efficiently as possible. They run at very high speeds and are more efficient and smaller than ordinary steam-engines of the same capacity.

The Internal-Combustion Engine

If a compact, powerful, mobile source of power is required, the internal-combustion engine is the choice. This type of engine can be adapted to the use of any fuel that can be vaporized, such as gasoline, alcohol, and kerosene. Coal gas is used in some engines, while the Diesel type employs cheap petroleum oils.



Chrysler Corporation

A Cut-Away Photograph of a Modern Internal Combustion Engine.

The Gasoline Engine

The type generally used is the four-cycle engine, so named because the piston makes four strokes for each explosion of gas in the cylinder. Once started it will run automatically as long as the three necessities of fuel, compression and spark are met. Smoothness of operation is accomplished by the use of a heavy flywheel and of several cylinders which fire at different times. Students will have little difficulty in understanding this engine after studying Fig. 14:14. Further treatment than this is beyond the scope of this text.

The Diesel Engine

This engine operates like a four-stroke gasoline engine but is without carburetor or electrical ignition system. Air is

forced into the cylinder and is compressed to about one-sixteenth of its volume and for that reason becomes hot. When oil is forced into this hot gas, it burns, without any need for a spark.

The Jet Engine

The last few years have seen the very rapid development of a new type of internal combustion engine, the Jet Engine. There are several types of such engines; the commonest, however, is the Turbo-Jet. Air is scooped into the intake at the front of the engine. It is compressed, and consequently heated, by a compressor. This heated air is driven under high pressure into the combustion chamber where fuel is injected in and combustion occurs. The hot expanding gases stream away at a high velocity. A small portion of their energy is used to drive the turbine which operates the compressor. Most of the energy is in the stream of hot gases which is ejected from the rear of the engine. The force exerted by this jet of hot gases (action) creates an equal and opposite force (reaction) that drives the plane forward.

Rockets are another type of modern reaction engine that operate very similarly to the jet engine described above. They differ in that they carry their own supply of oxygen to burn the fuel. As a result rockets can travel through outer space where there is no air. Inter-planetary travel, a thing long dreamed about, now seems to be becoming a real possibility.

III : 32 QUESTIONS

A

1. (a) Distinguish between quantity of heat and temperature.
   (b) State the factors that govern the quantity of heat possessed by a body.
2. (a) Define: calorie, British Thermal Unit, specific heat.
   (b) What quantity of heat is needed to:
   (i) warm 25 gm. of water from 13°C. to 27°C.?
   (ii) heat 37 lb. of water from 68°F. to 212°F.?
   (iii) heat 25 gm. of copper (S.H. = .092) from 22°C. to 100°C.?
3. (a) What is the principle of heat exchange in mixtures?
   (b) How long does heat exchange continue between two substances in contact?
   (c) What is the purpose of a calorimeter? How does it fulfil its purpose?
4. (a) Describe an experiment to find the specific heat of a metal.
   (b) When a 200 gm. mass of metal at a temperature of 85°C. is immersed in 300 gm. of water at 30°C., the final temperature is 33°C. Calculate the specific heat of the metal.
5. (a) Distinguish between boiling and evaporation.
   (b) Define melting-point and boiling-point.
6. (a) Define heat of fusion of ice and state its numerical value in the metric and British systems.
   (b) Describe how you would determine its value experimentally.
7. (a) How much heat will be released when 50 gm. of water at 0°C. freeze to ice at 0°C.?
   (b) How much heat will be absorbed in the melting of 20 gm. of ice at 0°C. to water at 0°C.?
   (c) How much heat will be required

to convert 80 gm. of ice at 0°C. to water at 25°C.?

8. (a) Define heat of vaporization of water.
(b) Why is a burn from steam much more severe than that from hot water?

9. (a) How much heat will be required to convert 50 gm. of water at 100°C. to steam at 100°C.?
(b) How much heat will be released when 15 gm. of steam at 100°C. are condensed to water at 100°C.?
(c) How much heat will be released when 35 gm. of steam at 100°C. are condensed to water and the water is cooled to 20°C.?

10. (a) Explain the principle of operation of the electric refrigerator.
(b) How is air liquefied?

B

1. How much heat is required to raise the temperature of 2 kg. of water from 25°C. to 75°C.?

2. How many B.T.U. will be absorbed when 30 gallons of water in a hot-water tank are heated from 70°F. to 200°F.? (1 gallon of water weighs 10 lb.)

3. How much heat is lost when 1.3 kg. of water are cooled from 90°C. to 20°C.?

4. How much heat in B.T.U. will be released when 15 gallons of water cool from 165°F. to 125°F.?

5. How many calories of heat must be supplied to heat 200 gm. of cast iron from 20.0°C. to 80.0°C.?

6. How much heat does a silver spoon weighing 30.0 gm. absorb when placed in a cup of coffee that raises its temperature from 20.0°C. to 80.0°C.?

7. How many grams of water at 85.0°C. must be added to 100 gm. of water at 10.0°C. to give a final temperature of 37.0°C.?

8. When 25 gm. of water at 100°C. are added to 50 gms. of water at 10°C., what is the final temperature?

9. When 200 gm. of metal at 100°C. are placed in 200 gm. of water at 15.0°C., the final temperature becomes 23.0°C. Calculate the specific heat of the metal.

10. A brass kilogram weight at a temperature of 90.0°C. is submerged in 440 gm. of water at 10.0°C. The final temperature is 24.0°C. Find the specific heat of the brass.

11. 49 gm. of water at 13°C. are contained in an aluminum calorimeter weighing 50 gm. If 35 gm. of glass at 87°C. are dropped into the calorimeter the temperature becomes 21°C. Find the specific heat of the glass.

12. In an experiment, 500 gm. of lead at 100°C. are placed in 100 gm. of water at 14°C. contained in a copper calorimeter weighing 80 gm. The final temperature is 25°C. Find the specific heat of the lead.

13. What mass of iron at 90.0°C. when added to 200 gm. of water at 15.0°C. contained in a copper calorimeter weighing 100 gm. will give a final temperature of 25.0°C.?

14. When 400 gm. of silver at 100°C. was placed in water at 16.0°C. contained in an aluminum calorimeter weighing 40.0 gm. the final temperature was 24.0°C. What mass of water was used?

15. Calculate the final temperature when 120 gm. of iron at 100°C. are added to 400 gm. of water at 10°C. in a copper calorimeter having a mass of 80 gm.

16. A copper calorimeter weighing 65 gm. contains 30 gm. of turpentine at 15°C. When 45 gm. of iron at 98°C. are placed in it, the temperature becomes 32°C. Calculate the specific heat of the turpentine.

17. How much ice at 0°C. can be melted by 1 kg. of water at 100°C.?

18. How much ice at 0°C. will be required

to cool 1 kg. of drinking-water from 15°C. to 0°C.?

19. What mass of ice at 0°C. will be required to cool 750 gm. of water from 35°C. to 10°C.?

20. When 5.0 gm. of ice at 0°C. are melted in 30 gm. of water at 25°C. the final temperature is 10°C. Find the heat of fusion.

21. A copper calorimeter weighing 55 gm. contains 90 gm. of water at 25°C. When 15 gm. of ice at 0°C. are melted in the water the resulting temperature is 11°C. Find the heat of fusion of ice.

22. In an experiment 203 gm. of water at 40°C. are contained in a calorimeter vessel weighing 50 gm. having a specific heat of .22. After ice at 0°C. was melted in the water the temperature became 25°C. and the mass 233 gm. Find the heat of fusion of ice.

23. If 15 gm. of ice at −20°C. are melted in 50 gm. of water at 40°C. and the resulting temperature is 10°C., calculate the specific heat of ice.

24. How many grams of water can be raised from freezing-point to boiling-point by the condensation of 5.0 gm. of steam?

25. To what temperature will 75 gm. of water at 25°C. be heated by the condensation of 3.0 gm. of steam?

26. When 6.6 gm. of steam at 100°C. are passed into 180 gm. of water at 6.0°C. contained in an aluminum calorimeter weighing 45 gm., the resulting temperature is 27°C. Find the heat of vaporization of water.

27. If 15 gm. of steam at 100°C. are added to 150 gm. of water at 20°C. in a calorimeter (S.H. = 0.10) weighing 75 gm. the final temperature is 74°C. Calculate the heat of vaporization of water.

28. When 160 gm. of water at 7.7°C., contained in an aluminum calorimeter weighing 126.2 gm., are heated by the condensation of 10.1 gm. of steam, the final temperature is 39.8°C. Find the heat of vaporization of water.

29. Find the resultant temperature when 8.0 gm. of steam at 100°C. are passed into a vessel of negligible mass containing 40 gm. of ice at 0°C.

30. Find the final temperature when 20 gm. of steam at 100°C. are passed into 240 gm. of water at 10°C. contained in an aluminum calorimeter weighing 150 gm.

31. What quantity of heat will convert 5 gm. of ice at −16°C. to steam at 100°C.?

32. When 45.0 gm. of iron at 95.0°C. are placed in a cavity in a block of ice at 0°C. and the temperature has dropped to 0°C., 6.0 gm. of ice are melted. Knowing the heat of fusion of ice, find the specific heat of iron.

33. An ice-water mixture weighing 200 gm. is contained in a calorimeter weighing 100 gm. (S.H. = 0.20). When 35 gm. of steam at 100°C. are added the temperature becomes 50°C. Calculate the mass of ice used.

CHAPTER 15 EXPERIMENTS IN HEAT

INTRODUCTION

Before commencing these experiments in heat, students should be familiar with the following.

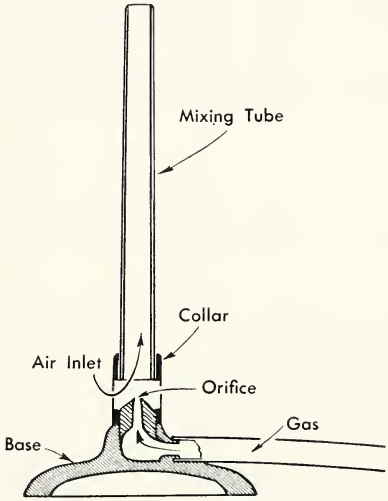


Fig. 15:1

A. The Use of the Bunsen Burner

1. **Structure of the Burner**

   Examine a Bunsen burner and identify the gas inlet, the orifice, the air-inlet valve, the mixing tube. Make a labelled diagram of the burner.

2. **Lighting the Burner**

   (a) Close the air inlet, turn on the gas and ignite it. Gradually open the air inlet until you have the desired flame.

   (b) If the flame "strikes back", i.e., burns at the bottom of the mixing tube, turn off the gas and repeat (a) above.

3. **Regulating the Size and Temperature (Colour) of the Flame**

(a) The size of the flame may be changed by increasing or decreasing the supply of gas.

(b) When first lit, the flame is yellow and its temperature is too low for most purposes.

When the air inlet is gradually opened, the colour changes from yellow, through blue to nearly colourless, and the temperature increases until it is a maximum at the last stage.

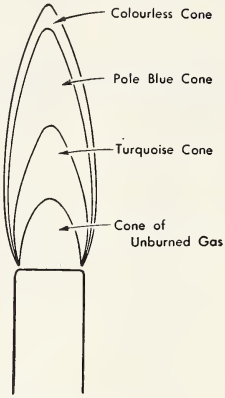


Fig. 15:2

4. **The Structure of the Flame**

Fig. 15:2 shows the various regions (cones) of a Bunsen flame. An object to be heated is held just above the turquoise cone.

B. The Use of the Thermometer

1. Examine the instrument and find the centigrade scale. (Some thermometers have centigrade and Fahrenheit scales.)
2. Wait until the liquid has come to rest before taking a reading.
3. Adjust the thermometer so that you are able to view the top surface of the liquid at right angles in order to avoid the error of parallax.
4. Take readings to a fraction of a degree.

EXPERIMENT 1

To study the expansion of solids. (REF. SEC. III:5)

Apparatus

Bunsen burner, ball-and-ring apparatus, cold water.

Method

1. Try to pass the ball through the ring when both are cold.

2. Heat the ball strongly and try to pass the ball through the ring again.
3. Cool the ball by placing it in cold water and again try to pass it through the ring.

Observations

What do you observe in the above steps?

Conclusion

What is the effect of heating and cooling on the volume of a solid?

Questions

1. What would be the probable effect of heating the ring and trying to pass the heated ball through it?
2. What would be the probable effect of chilling the ring in a freezing mixture and trying to pass the ball through it?
3. By means of labelled diagrams, show how you would demonstrate the effect of heating and cooling on the volume of (a) a liquid, (b) a gas.

EXPERIMENT 2

To compare the expansion of different metals when heated. (Ref. Sec. III:5)

Apparatus

Bunsen burner, compound bar consisting of strips of copper and iron fastened together, cold water.

Method

1. Heat the long straight compound bar in the Bunsen-burner flame and note any change.
2. Cool the bar in cold water and again note the change.

Observations

1. Describe the changes that occurred in parts 1 and 2.
2. Which metal was on the outside of the curve?

Explanation

Account for the changes.

Conclusion

What is the relative amount of expansion and contraction that occurs when different metals undergo the same change in temperature?

Question

Make a labelled diagram to show how to use a compound bar as a thermostat to control an oil burner and thus regulate the temperature in a room.

EXPERIMENT 3

To study the transfer of heat by conduction. (REF. SEC. III:13)

Apparatus

Bunsen burner, metal rod about 12 in. long with a wooden handle, a conductometer (Fig. 13:1), wax.

Method

1. Place drops of wax at three-inch intervals along the length of the long metal rod. Hold it by the wooden handle and heat the end of the rod strongly in the flame of the burner.
2. Place drops of wax at equal intervals along the rods of the conductometer and heat the metals simultaneously at the point where the rods meet.

Observations

1. (a) What happens to the wax in part 1?
   (b) Is there any change noted in the temperature of the wooden handle?
2. State the differences observed in each metal rod in part 2.

Conclusions

1. State the meaning of the term conduction of heat. Explain how it occurs.
2. What have we learned about the heat conductivity of different metals? How does wood compare with metals in this regard?
3. List the metals studied in order of their relative heat conductivities.

Questions

1. How do metals compare with other substances in heat conductivity?
2. What use is made of the conductivity of heat through metals?
3. Why are liquids and gases very poor conductors of heat?
4. List some materials that are good insulators and state where they are used for this purpose.

EXPERIMENT 4

To study the transfer of heat by convection. (REF. SEC. III:14)

A. IN LIQUIDS

Apparatus

A large beaker, retort stand, ring, Bunsen burner, cold water, potassium permanganate.

Method

Fill the beaker with water and place it on the ring attached to the stand. Make sure that the water is at rest. Drop a crystal of potassium

permanganate into the water near the edge. Using the tip of the low Bunsen flame, heat the liquid beneath the crystal.

Observations

Describe all phenomena.

Explanation

Account for the changes observed.

B. IN GASES

Apparatus

A candle, smoke-paper, convection apparatus (Fig. 13:6b).

Method

Light the candle and place it beneath one of the chimneys. Close the glass front. Hold a piece of lighted smoke-paper above the other chimney.

Observations

State what occurs.

Explanation

Account for these results.

Conclusion

State the meaning of the term convection currents and explain how they occur.

Question

Show by means of a diagram how heat is transferred from the furnace to an upper room in a home heated by (a) a simple hot-water system (b) a simple hot-air system.

EXPERIMENT 5

To compare the abilities of dull, dark and shiny, light surfaces to emit radiant energy. (Ref. Sec. III:15(b)

Apparatus

A differential thermometer with both bulbs blackened with soot from a candle, metal vessel with one side blackened and the other polished, some boiling water.

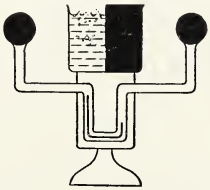


Fig. 15:3

Method

Mark the levels of the coloured liquid in the arms of the differential thermometer and then place the metal vessel full of boiling water midway between the bulbs. Note any change in the levels of the coloured liquid.

Observations

What is observed?

Explanation

Account for your observations.

Conclusion

What effect has the nature of the surface of an object on its ability to emit radiant energy?

Questions

1. Why is this apparatus called a differential thermometer?
2. Why should tea-pots be shiny rather than dull?

EXPERIMENT 6

To compare the abilities of dull, dark and shiny, light surfaces to absorb radiant energy. (REF. SEC. III:15(c)

Apparatus

A differential thermometer with one bulb shiny and one blackened, dull, dark metal vessel, supply of boiling water.

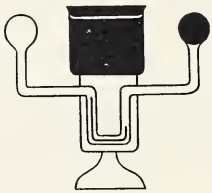


Fig. 15:4

Method

Mark the levels of the coloured liquid in the differential thermometer and place the vessel filled with boiling water midway between the two bulbs. Note any changes in the levels of the liquid.

Observations

What is observed?

Explanation

Account for the observations.

Conclusion

What effect has the nature of the surface on its ability to absorb radiant energy?

Questions

1. In experiment 5, why were the bulbs of the differential thermometer darkened?
2. In experiment 6, why is a dull, dark vessel used?
3. Why do people wear dark clothing in winter and light-coloured clothes in summer?
4. Examine a radiometer and make a labelled diagram of it. Note and explain what happens when a source of radiant energy is brought near it.

EXPERIMENT 7

To determine the specific heat of a metal. (Ref. Sec. III:24)

Apparatus

A quantity of copper (or lead) shot, balance and weights, flask, test-tube, water, retort stand, ring, gauze, Bunsen burner, calorimeter, two thermometers.

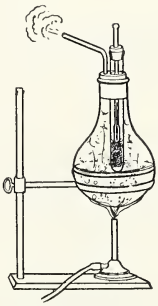


Fig. 15:5

Method

1. Fill the test-tube three-quarters full of shot and carefully insert the bulb of a thermometer into it. Place the shot and its container in the flask and boil the water while carrying out parts 2, 3 and 4. Note the temperature of the shot to within a fraction of a degree after the mercury stops rising.
2. Find the mass of the inner vessel of the calorimeter and stirrer. Record the specific heat of the metal of which both are made.
3. Place about 100 ml. of cold tap-water whose temperature is slightly lower than room temperature in the inner vessel. Find the mass of the vessel and water, and determine the mass of the water.

4. Place the inner vessel and contents into the outer vessel. Cover with the lid. Stir the water and take its temperature.
5. Open the calorimeter, add the shot to the water, close it, and after stirring the mixture, again take its temperature.
6. Find the mass of the vessel, stirrer, and contents, and determine the mass of the shot.

Observations

1. Temperature of the shot =
2. Mass of the inner vessel and stirrer =
3. Mass of the inner vessel, stirrer and water =
4. Initial temperature of the vessel and water =
5. Final temperature of the mixture of water and shot =
6. Mass of the vessel, stirrers and mixture =

Specific heat of the vessel =
Specific heat of the water =
Let the specific heat of the shot = x

Calculations

Study the worked example in Sec. III:24 and calculate the specific heat of the metal from the observations recorded above.

Conclusions

1. What is your experimental value?
2. What is the class average?

Questions

1. What is the percentage error?
2. What are the sources of error in this experiment?
3. Why is it desirable to have the initial temperature a few degrees lower than room temperature?

EXPERIMENT 8

To determine the heat of fusion of ice. (REF. SEC. III:27)

Apparatus

Quantity of ice, paper towels, thermometer, balance and weights, quantity of water at about 10C.° warmer than room temperature, calorimeter.

Method

1. Find the mass of the inner vessel and stirrer.
2. Place about 100 ml. of the warm water in the vessel and again find the mass.
3. Place the inner vessel in the outer one. Cover with the lid. Stir the water and take its temperature, estimating it to a fraction of a degree.

4. Wipe dry about 25 gm. of ice with the paper towels and quickly drop it into the warm water. Replace the cover and stir until the ice has melted completely. Record the lowest temperature reached by the water.
5. Find the mass of the vessel, stirrer, and contents, and determine the mass of the ice.

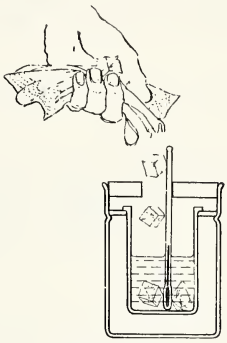


Fig. 15:6

Observations

1. Mass of inner vessel and stirrer =
2. Mass of inner vessel, stirrer and water =
3. Initial temperature of the water and vessel =
4. Final temperature of the mixture of original water and melted ice =
5. Mass of vessel, stirrer and the mixture =

Specific heat of the vessel =
Specific heat of the water =
Initial temperature of the ice =
Let the heat of fusion of ice = x

Calculations

Study the worked example in Sec. III:27 and calculate the heat of fusion of ice from the observations recorded above.

Conclusions

1. What is the experimental value for the heat of fusion of ice?
2. What is the class average?

Questions

1. What is the percentage error?
2. What are the sources of error in this experiment?
3. Why is it desirable to have the initial temperature a few degrees higher than room temperature?
4. Why do we dry the ice before placing it in the water?

EXPERIMENT 9

To determine the heat of vaporization of water. (REF. SEC. III:29)

Apparatus

A calorimeter, quantity of water at about 15C.° below room temperature, thermometer, Bunsen burner, retort stand, ring, gauze, steam-boiler, steam-trap, rubber connectors (Fig. 14:6).

Method

Place the boiler containing water on the ring of the retort stand and heat it.

1. Find the mass of the inner vessel and stirrer.
2. Put about 100 ml. of the cold water into the inner vessel and find the combined mass.
3. Place the inner vessel in the outer one and put on the lid. Stir the water and take its temperature, estimating it to a fraction of a degree.
4. Connect the steam-trap with the boiler and conduct steam into the water. Stir constantly until its temperature has risen as much above room temperature as it was originally below it. Discontinue passing steam into the water and take the highest temperature reached by the water.
5. Find the mass of the inner vessel and contents.

Observations

1. Mass of inner vessel and stirrer =
2. Mass of inner vessel, stirrer and water =
3. Initial temperature of the mixture =
4. Final temperature of the mixture =
5. Mass of vessel, stirrer and mixture =

Specific heat of the vessel =
Specific heat of the water =
Initial temperature of the steam =
Let the heat of vaporization of water = x

Calculations

Study the worked example in Sec. III:29 and calculate the heat of vaporization of water from the observations recorded above.

Conclusions

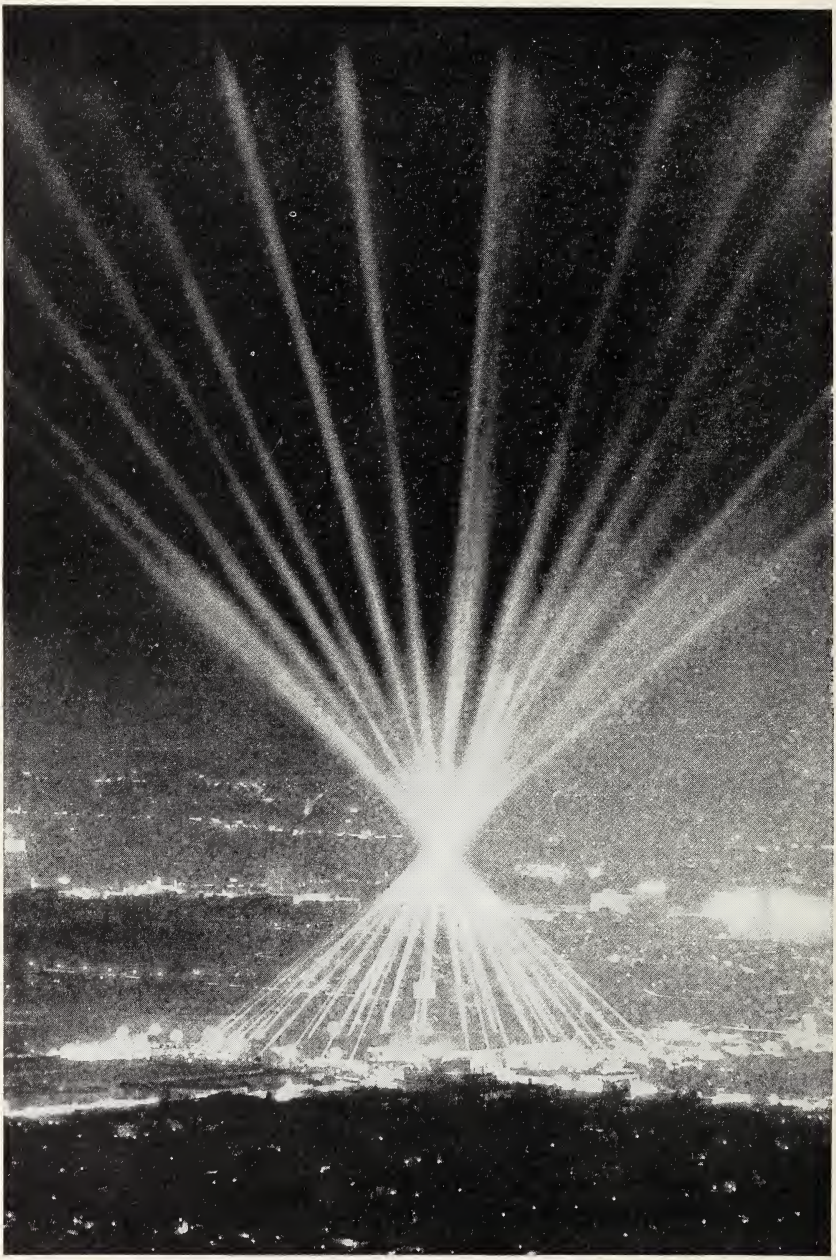
1. What is the experimental value for the heat of vaporization of water?
2. What is the class average?

Questions

1. What is the percentage error?
2. What are the sources of error in this experiment?
3. How may the effect of the sources of error be minimized?
4. Why is it important to use the steam-trap?

UNIT IV

LIGHT



Wheeler Newspaper Syndicate

These Searchlights Create an Interesting Construction, Showing both a Converging and a Diverging Pencil of Light Rays.

CHAPTER 16 NATURE AND PROPAGATION OF LIGHT

IV : 1 NATURE OF LIGHT

Light is that agency which affects the eye and produces the sensation of "seeing" (sight). That branch of physics that covers all the phenomena pertaining to light is called **Optics** (Greek, *ops*—eye). Some knowledge of light existed from very early times, though this was limited primarily to effects rather than to any fundamental understanding.

As to the nature of light, the early Greeks believed it to consist of streams of minute particles of some sort. There was considerable debate as to whether these particles originated in the eye or in the object viewed. Plato (428-348 B.C.) and Euclid (about 300 B.C.) held to the idea that invisible feelers were emitted from the eye, and that the eye sees a body somewhat as the hand may feel it with a rod. The Pythagoreans, Aristotle (284-322 B.C.) in particular, opposed this view and taught that light consisted of minute particles projected into the eye from the object. Both these conflicting ideas were mere guesses and as such were worthless. However, in the eleventh century Alhazen, an Arabian physicist, provided definite evidence showing that the cause of vision proceeded from the object and not the eye. Even to-day, much mystery still surrounds the nature of light (Sec. IV: 7). In view of the fact that light can be produced from other forms of energy, e.g., heat energy, and that light can be transformed into other forms of energy, e.g., electricity (Sec. V:82), we shall simply say that **light is a form of energy.**

IV : 2 SOURCES OF LIGHT

Few objects give out light and these are termed **luminous bodies.** Most objects are non-luminous, becoming visible only when they reflect light from some outside source to our eyes (Fig. 16:1).

Our main source of light is the sun. When we think how important the sun has always been in human affairs, it is not surprising that in prehistoric times it became a prime object of worship. History records the ancient Egyptian Sun-god, Ra, and an ancient Persian god of light, Ahura-mazda. The terms "ray" of light, and "mazda" lamps are derived from these names.

Many objects are rendered luminous by being heated to incandescence. This may be accomplished by mechanical means as shown when sparks are produced by friction between flint and steel in a gas-lighter; by resistance to an electric current in the thin wire used in electric-light bulbs; and by chemical action as in the burning of a fuel. Some objects are luminous at ordinary tem-

Fig. 16:1 Self-Luminous and Non-Luminous Objects.

Tigerstedt Studios, Calgary

peratures, a stick of phosphorus, for example, and fluorescent bodies. Then there is the glow produced by the discharge of electricity through certain gases, e.g., neon tubes. Another interesting example of "cold light" is that produced by fireflies, and by certain deep-sea fish. Probably such light is produced by chemical means.

IV : 3 TRANSMISSION OF LIGHT

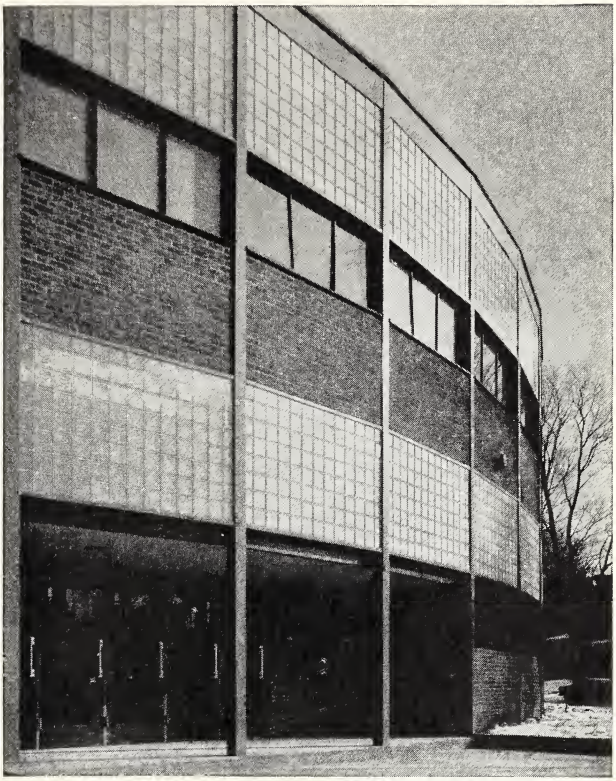
Unlike sound, light does not require a material medium for its transmission. Evidence in support of this is supplied by the fact that light travels through a vacuum in coming to us from objects in space, and from the glowing filament of an evacuated tube. Further evidence was provided in experiment 4, chapter 10, where we could not hear the bell when the air was evacuated from the jar yet could still see it ringing.

Various media differ in their ability to transmit light. **Transparent** objects such as air, glass and water transmit light so readily that it is easy to see through them. A **translucent** substance, such as frosted glass or oiled paper, is one that transmits some light, but in doing so distorts or scatters the light so that we cannot see clearly objects on the other side. **Opaque** substances, like wood, do not transmit light at all and hence we cannot see through them.

It is common knowledge that light travels in straight lines. Our inability to see around corners, the formation of shadows, and other examples point to this conclusion. This behaviour of light is termed **rectilinear propagation**. Knowing this, we represent a path of light by a straight line called a **ray.** (Note: the light that travels along this path is also called a ray.) The direction in which the light is travelling is indicated by arrow-heads placed on the rays. Several parallel rays form a **beam** of light. Rays of light proceeding towards a point form a **converging pencil;** when they spread out from a point they form a **diverging pencil** (Fig. 16:2).

IV : 4 PIN-HOLE CAMERA

The pin-hole camera is an interesting



Glass bricks are used in the construction of many modern buildings. What are the advantages?

Canadian Pittsburgh Industries Ltd.

application of the rectilinear propagation of light. It consists of an opaque box, having a small hole (pin-hole) in the middle of one end, and a translucent screen (piece of ground glass, or oiled paper) at the other. If a lighted candle is placed a little distance in front of the pin-hole, an inverted image of the candle will be seen on the translucent screen.

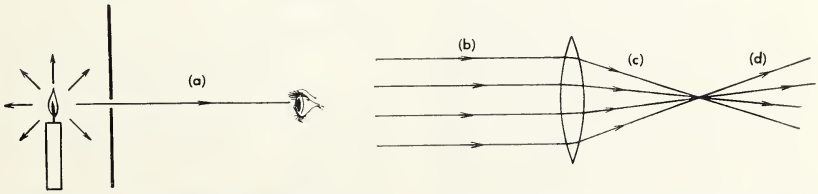


Fig. 16:2 Rectilinear Propagation of Light (a) Ray (b) Beam (c) Converging Pencil. (d) Diverging Pencil.

This kind of image is formed as a result of very narrow diverging pencils of light from each point of the object passing through the pin-hole, and producing small patches of light, identical in shape to the pin-hole, on the screen.

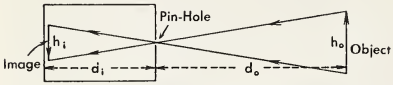


Fig. 16:3 The Pin-Hole Camera.

The resulting image is formed by a large number of these overlapping patches of light, producing an exact replica of the original object. Such an image is a real image. The image so obtained will have a somewhat blurred, or out-of-focus appearance due to the circular edges of each patch of light not entirely overlapping. The larger the pin-hole the brighter will be the image on the screen, but the more blurred will be its edges. The image is inverted because the light rays cross at the pin-hole (Fig. 16:3).

The size of the image is governed by the size of the object, its distance from the camera, and the distance of the image from the pin-hole (Chap. 21, Exp. 1).

$$\frac{\text{Size of Image}}{\text{Size of Object}} = \frac{\text{Distance of Image}}{\text{Distance of Object}}$$

$$\frac{Hi}{Ho} = \frac{Di}{Do}$$

A consideration of the equiangular (or similar) triangles formed by the rays of light as shown in Fig. 16:3 should establish these relationships fairly readily.

If we replace the translucent screen with a light-sensitive paper, or photographic plate, quite acceptable photographs of distant objects can be obtained. A very long exposure is necessary, however, because of the small amount of light admitted through the pin-hole.

IV : 5 SHADOWS AND ECLIPSES

A shadow is the dark space behind an opaque object, an area from which light has been partially or completely excluded. An opaque object in front of a point source of light will cut off all the light, and a sharply defined shadow is produced. If the light comes from a larger source, the shadow will vary in intensity, the dark central portion of the shadow which receives no light from any part of the source being the **umbra** (Fig. 16:4a), the lighter shadow surrounding the umbra which receives some light being the **penumbra** (Fig. 16:4b).

An eclipse of the sun is an interesting shadow phenomenon caused when the moon comes between the sun and earth (Fig. 16:5). A person located in the moon's umbra will observe a **total eclipse** of the sun. If in the moon's

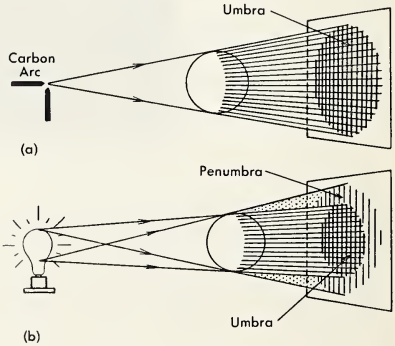


Fig. 16:4 Shadows (a) Using Point Source. (b) Using Large Source.

penumbra, he will be able to see part of the sun. The latter is called a **partial eclipse** of the sun. Because the moon's orbit around the earth is slightly elliptical its distance from the earth varies. Thus it occasionally happens

that the moon comes between the sun and the earth at a time when its umbra does not reach the surface of the earth. A person located on the earth below the tip of the moon's umbra would see a ring of the sun around the edge of the moon. Such an eclipse is called an **annular eclipse** of the sun and occurs very rarely.

Eclipses of the moon also occur, and at fairly frequent intervals. The moon is a non-luminous body, and is seen only when sunlight is reflected from its surface to the earth. The full moon occurs when the moon is on the opposite side of the earth from the sun. At such a time the moon may pass through the earth's shadow and be eclipsed. A partial eclipse of the moon is caused when it

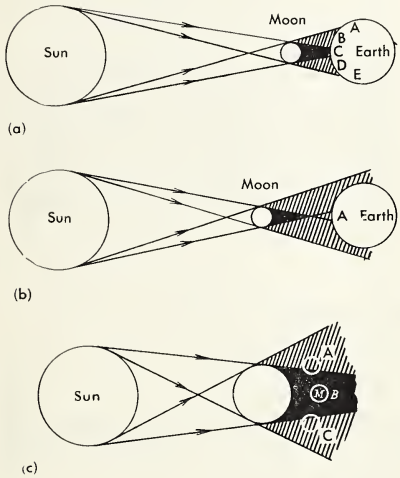


Fig. 16:5 Eclipses.
(a) Total and Partial Eclipse of the Sun.
(b) Annular Eclipse of the Sun.
(c) Eclipse of the Moon.

is partly in the earth's umbra, and a total eclipse when it is completely in the earth's umbra. When in the earth's penumbra, the moon is not eclipsed, but only less bright as it receives, and hence reflects, less light from the sun.

IV : 6 VELOCITY OF LIGHT

It has long been suspected that light travels with a finite velocity, but early attempts to measure this velocity were

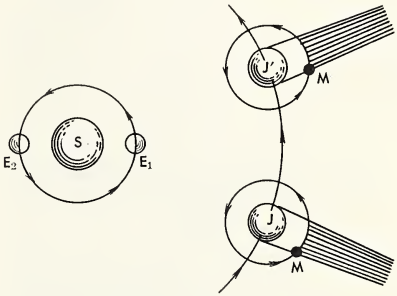


Fig. 16:6 Velocity of Light Using the Moons of Jupiter.

too crude to be successful. The first reasonably accurate value was obtained by a young Danish astronomer Olaus Römer in 1676. He found that intervals between the successive eclipses of one of the moons of the planet Jupiter were longer when Earth was receding from Jupiter (going from E_1 to E_2) and shorter when Earth was approaching (going from E_2 to E_1, Fig. 16:6). Römer ascribed the discrepancy to the time required for light to travel across the diameter of the earth's orbit. The time-lag was found to be about 16.5 minutes or approximately 1000 seconds. Since the diameter of the earth's orbit is about 186,000,000 miles, the velocity of light is found to be 186,000 miles per second.

The first determination of the velocity of light over short distances on the earth was made in 1849 by A. H. Fizeau. His method was to pass a beam of light through one of the gaps in a toothed wheel, and reflect it back on its path from a mirror three or four miles away

(Fig. 16:7). When the wheel was at rest, the return beam passed back through the same gap and was visible on the other side. When the wheel was rotated rapidly, a speed could be found at which

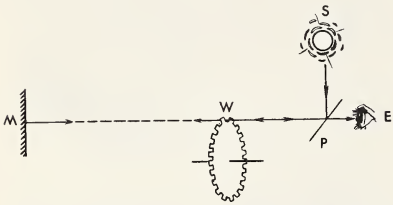


Fig. 16:7 Scheme of Fizeau's Apparatus for Measuring Velocity of Light.

the return way was blocked by the next tooth. The time spent by the wheel in spinning through this small part of a revolution, is also the time required for the light to travel to the distant mirror and back again. Hence, knowing these facts, the velocity of light could be easily calculated.

A better method was devised by J. L. Foucault in 1850, who used a rotating mirror instead of a toothed wheel. This method was used in more elaborate form by A. A. Michelson in 1926, with an eight-sided mirror and a considerably increased light path (Fig. 16:8). More recently, Michelson in collaboration with others, set up a mile-long evacuated tube with a mirror arrangement for causing a beam of light to traverse this path back and forth many times before being observed. Again using a rotating-mirror method, they obtained a quite accurate value for the velocity of light in a vacuum which was found to be slightly higher than its velocity in air.

The approximate values for the velocity of light, C, in air are:

C = 300,000 kilometres per second or
3×10^{10} centimetres per second
or C = 186,000 miles per second.

The velocity of light is a most important physical determination, since it is the speed with which many forms of energy travel through space. It is interesting to note that the vast distances of space are measured in terms of the **light-year.** This is the distance travelled

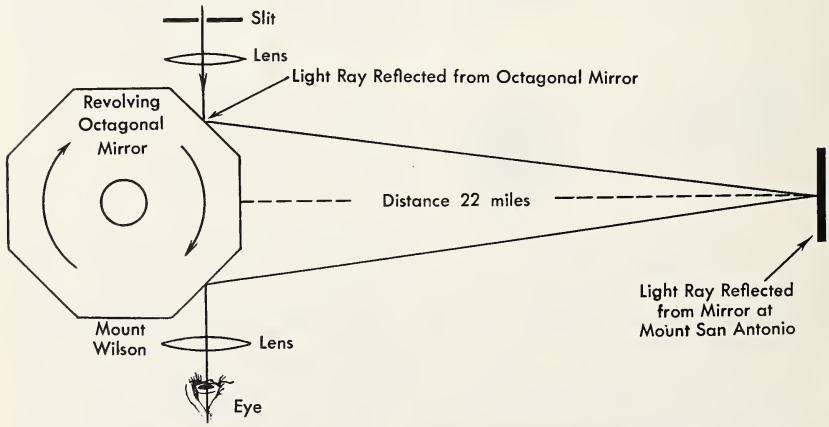


Fig. 16:8 Velocity of Light, Michelson's Method.

by light in one year. Some of the more distant stars and nebulae are so remote from the earth that the light by which we now see them set out on its journey to the earth thousands of years ago.

IV : 7 THEORIES OF LIGHT

The first rational attempt to explain the propagation of light was made by Sir Isaac Newton (1642-1728). His theory, the **Emission** or **Corpuscular Theory**, postulated that light energy was conveyed through space by a swiftly moving stream of particles or corpuscles shot out from the luminous body. Most of the properties of light known at Newton's time such as the rectilinear propagation of light and the effects of reflection (Chap. 17) and of refraction (Chap. 18) were adequately accounted for by this theory.

A rival postulate was put forward by Christian Huygens (1629-1695), the son of a Dutch diplomat and poet. He sought to explain the behaviour of light in terms of waves, and hence his theory is called the **Wave Theory**. Again, reflection and refraction were readily explicable in terms of this wave theory. Difficulties were encountered, however, when seeking to explain the rectilinear propagation of light, and also in the need for postulating the existence of a medium, the ether, completely filling space in which the waves could travel. As a result, the wave theory remained undeveloped and Newton's corpuscular theory was generally accepted.

Early in the nineteenth century, Thomas Young (1773-1829), and A. J. Fresnel (1788-1827), provided valuable experimental support for the wave theory of light. They were able to show that two beams of light could be made to interfere with and to reinforce each other, thereby producing alternate dark and bright lines. This could only be explained by "superposition of waves". At one position when in opposite phase, a crest with a trough, these waves produce a dark line. At another position when in the same phase, a crest with a crest, or a trough with a trough, they produce a bright line. (Compare with superposition of sound waves, Sec. II:6.)

Another line of experimental support in favour of the wave theory was to show that the velocity of light is smaller in the denser of two media. The corpuscular theory had predicted the exact reverse of this.

Recent work seems to favour a combination of the corpuscular and wave theories in the explanation of many of the observed effects. This theory called the **Quantum Theory**, was first devised by Max Planck in 1901. According to this theory, light is emitted by the atoms of a luminous body in separate packets or bundles of energy called quanta or photons. Probably one or more of the electrons revolving about the nucleus of an atom (Sec. V:12) can be made to jump from one orbit or "energy level" to another. As they do so, one or more quanta of energy, or photons are emitted. This energy radiates from the luminous body as electromagnetic waves (Sec. IV:38). The energy content of a photon determines the length and frequency of the wave, and hence the colour of the light observed.

IV : 8

QUESTIONS

A

1. (a) Define optics.
   (b) What is the nature of light?
2. (a) Distinguish between "luminous" and "illuminated" objects.
   (b) How may objects be rendered luminous?
3. (a) What evidence have we to prove that light can travel through a vacuum?
   (b) Distinguish between opaque, translucent and transparent substances. Give examples of each.
4. (a) What is meant by the "rectilinear propagation of light"? Discuss evidence in support of it.
   (b) Define: ray, beam, converging pencil, diverging pencil.
5. (a) Describe the image obtained in a pin-hole camera.
   (b) Explain how it is produced.
   (c) Name three factors that govern its size.
   (d) The length of a pin-hole camera is 10 in. An object 6ft. high is placed at a distance of 30 ft. from the pin-hole. Calculate the size of the image produced.
6. (a) Define: umbra, penumbra.
   (b) Construct a labelled diagram to show how both total and partial eclipses of the sun are produced.
7. (a) What is the velocity of light in air?
   (b) How many minutes are required for light to travel from the sun to the earth (93×10^6 miles)?
   (c) What is a light-year?
8. What contributions did Newton, Huygens and Planck make to a theory of light?

1. Calculate the distance of an object 12 ft. high whose image is 4 in. high in a pin-hole camera 10 in. long.
2. Calculate the size of the image of a tree 30 ft. high, 100 yards distant, in a pin-hole camera 8 in. long.
3. Calculate the height of a building 300 metres distant which produces an image 2.5 cm. high in a pin-hole camera 2.0 in. long.
4. How long does it take for light to travel from the moon to the earth (24×10^4 miles)?
5. Calculate the number of (a) miles, (b) kilometres in 1 light-year.
6. Sirius, the brightest star in the sky, is 9 light-years away. How far away is this in miles?
7. Our nearest neighbour among the stars, excepting the sun, is Proxima Centauri which is about 25×10^{12} miles away. How long does it take for light from this star to reach us?

CHAPTER 17 REFLECTION OF LIGHT—MIRRORS

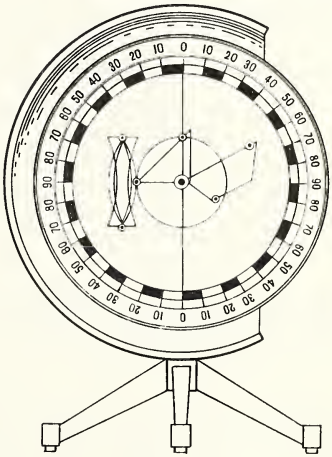


Fig. 17:1 The Optical Disc, for Demonstrating the Laws of Optics.

IV : 9 THE LAWS OF REFLECTION

In section IV:2, we learned that most objects are made visible when light falling on them is reflected back to our eyes. The rays of light that fall upon a body are called **incident rays**, while those that are sent back by the body are called **reflected rays**.

A **mirror** is a smooth, highly polished surface, designed to reflect a maximum amount of light. Mirrors usually consist of pieces of glass silvered on one surface. Some are flat and are called **plane mirrors**, while others are called

Reflections on a Lake.

Star Newspaper Service

curved mirrors. However, any smooth surface, such as polished metal, polished wood, or still water, will serve as a mirror.

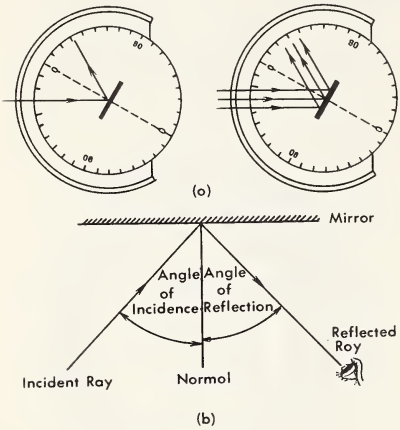


Fig. 17:2 Reflection of Light by a Plane Mirror (a) Using Optical Disc. (b) Terms.

To study reflection of light and other optical phenomena an optical disc is used (Fig. 17:1). This consists of a circular flat disc, graduated in degrees, to which various pieces of optical equipment can be fastened by means of thumb-screws. The disc can be turned about a horizontal axis by means of a handle fastened to the back. Surrounding the disc is an opaque collar in which is a window containing one or more horizontal slits.

Mount a plane mirror at the centre of the disc, with the face of the mirror at right angles to the zero line marked on the disc (Fig. 17:2). Allow a ray of light from a lantern to pass through a single slit in the window of the optical disc so that it falls upon the mirror. Adjust so that the **point of incidence** coincides with the point where the zero line meets the mirror. This line at right angles to the reflecting surface and meeting it at the point of incidence is called the **normal.** Rotate the disc and thus cause the incident ray to strike the mirror at different angles. In each case note the direction of the reflected ray and compare the size of **angle of incidence** (the angle between the incident ray and the normal), with that of the **angle of reflection** (the angle between the reflected ray and the normal). In each case these two angles will be found to be equal, and the incident ray, the reflected ray and the normal will all be found to be in the plane of the disc. Hence we can state the two laws of reflection as follows:

First Law: The angle of reflection always equals the angle of incidence
or $\angle r = \angle i$

Second Law: The incident ray, the normal, and the reflected ray all lie in the same plane.

These laws are quite simple and straightforward. We apply them daily in games such as handball, tennis and basketball where the bounce of a ball is utilized. Experiment 2, chapter 21, is an alternative method for proving these two laws of reflection.

IV : 10 REGULAR AND DIFFUSE REFLECTION

When parallel rays fall upon a smooth reflecting surface, such as a plane mirror, they form the same angle of incidence with the surface, and in consequence they will be reflected as a beam of parallel rays (Fig. 17:3a). Such reflection is called **regular reflection** and often produces undesirable glare. For example, one finds it difficult to read from a glazed paper in sunlight.

Diffuse or **irregular reflection** occurs

when light strikes a rough surface (Fig. 17:3b). Such a surface may be considered to be composed of a large number of tiny, flat surfaces that face in all directions. Thus when parallel rays of light strike such a surface, the individual rays are scattered or diffused due to their being reflected in different directions.

To avoid glare it is often necessary to promote diffusion of light. Unglazed paper is used for newspapers, and for

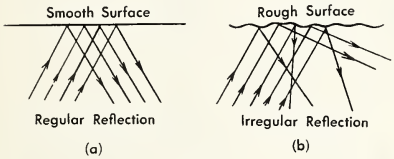


Fig. 17:3 Regular and Diffuse Reflection.

wall-papers. Frequently the woodwork in our homes is left with a dull finish. These, and other devices, all cause diffuse reflection of light.

Diffusion, and hence the elimination of glare, is also obtained by transmission of light through frosted or opalescent light bulbs, and lamp-shades. Prism glass and other types of roughened glass in windows serve the same purpose.

IV : 11 IMAGES IN PLANE MIRRORS

Mirrors have many and varied uses. Large plate-glass mirrors are frequently placed on the walls of our homes and of public rooms to give an impression of spaciousness. Rear-view mirrors are now compulsory in all automobiles. Mirrors are often used in scientific instruments to reflect light onto a scale, in projectors to intensify the light beam, in the view-finder of reflex cameras, in periscopes, and the like. In view of such widespread uses, it should be of real interest to us to study the images produced by plane mirrors (Fig. 17:4).

On doing experiment 3, chapter 21, you will learn the following facts about images in plane mirrors:

The Position of the Image. The image is as far behind the mirror as the object is in front, and a line joining the two passes through the mirror at right angles.

The Characteristics of the Image. The image is the same size as the object. It is a virtual image, that is, it only

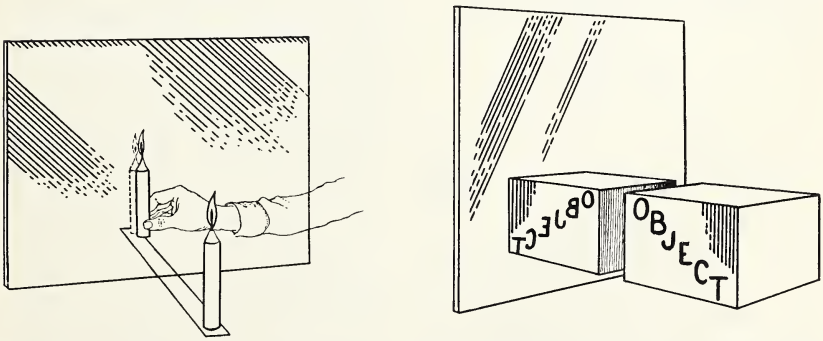


Fig. 17:4 Images in a Plane Mirror (a) The Position and Characteristics of the Image. (b) Lateral Inversion.

appears to be there. No light emanates from it. Such an image cannot be projected onto a screen. The image is vertically erect, but laterally inverted. When we say "laterally inverted" we mean that the right and left sides are interchanged (Fig. 17:4b).

Note that when the mirror is horizontal, the image is vertically as well as laterally inverted. Recall what you observe on looking into a still body of water to verify this fact.

IV : 12 TO LOCATE IMAGES IN PLANE MIRRORS

These phenomena observed experimentally can be shown to be true as a geometrical consequence of the laws of reflection, Sec. IV:9. Let us consider the simplest possible case, that of a point object, *O*, the image of which, *I*, is viewed by an eye *BD* (Fig. 17:5). *O* is sending out light rays in all directions.

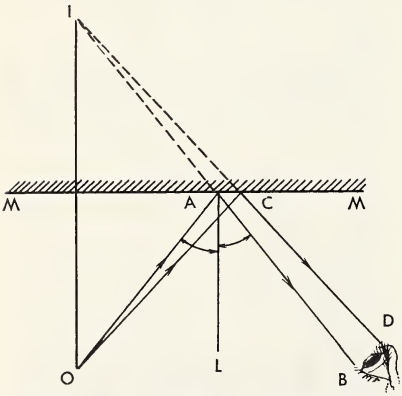


Fig. 17:5 To Locate the Image of a Point in a Plane Mirror.

Only those lying between *OAB* and *OCD* enter the pupil of the eye after being reflected from the mirror. The reflected rays *AB* and *CD* appear to be coming from *I*, their point of intersection.

In order to locate the image of an object in a plane mirror geometrically, the following construction is necessary (Fig. 17:6). From each point of the

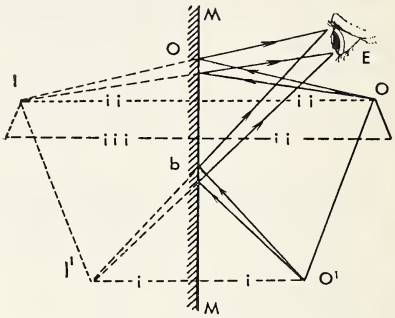


Fig. 17:6 To Locate the Image of an Object in a Plane Mirror.

object, draw a perpendicular to the mirror, and extend it an equal distance behind the mirror. Join the ends of all such lines and you will have an outline of the image of the object. Using the half arrow (⤵) enables you to indicate lateral inversion nicely. To show how the eye sees the image place a diagram of an eye on the same side of the mirror as the object. Draw a cone of rays from the tip of the image to just fill the pupil of the eye. Draw two light rays from the tip of the object to the two points on the mirror where the previous rays met the mirror. Put arrows on the real light rays as shown. Repeat this same procedure for each point on the object. Thus the eye is receiving light that appears to originate from the virtual image behind the mirror, but actually comes from the object.

In all diagrams, use faint lines for construction, dotted lines for imaginary rays or virtual image, and solid lines for real rays, real image, object, etc.

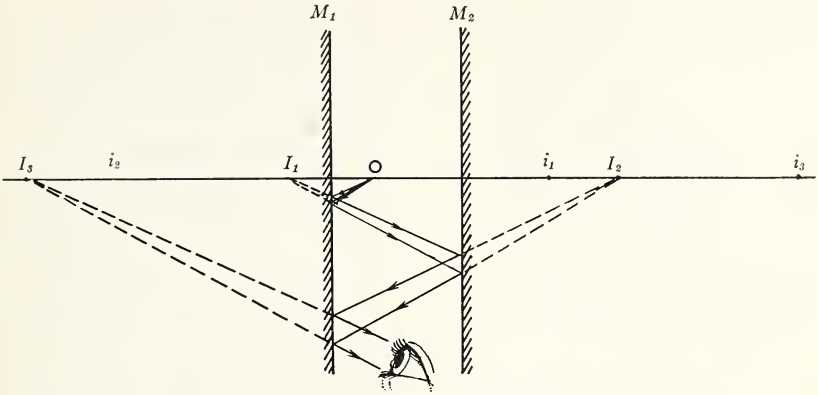


Fig. 17:7 Images in Parallel Mirrors.

IV : 13 PLANE MIRROR SYSTEMS

1. Parallel Mirrors

On looking into a mirror facing a parallel mirror on the opposite wall of a room, such as is used in barber shops, a very large number of images of the room can be seen stretching away almost endlessly. To discover how these are formed study Fig. 17:7 carefully.

A series of images representing the side of O facing mirror M_1 are formed (I_1, I_2, I_3,) and also a series of images representing the side of O facing mirror M_2 (i_1, i_2, i_3). These multiple images are due to the image formed in one mirror, acting as the object, which in turn forms an image in the second mirror, and so on. Since some light is absorbed at each reflection, each succeeding image is fainter than the one preceding.

2. Mirrors at Right Angles

When two mirrors are placed at right angles to each other (Chap. 21, Exp. 4), three images of an object will be observed (Fig. 17:8). I_1 and I_2 are images of O in mirrors M_1 and M_2. I_3 is the image of I_1 in the mirror M_2 produced (M_2 produced is really an image of M_2 in M_1) and of I_2 in mirror M_1 produced, these two images coinciding. How the eye sees these

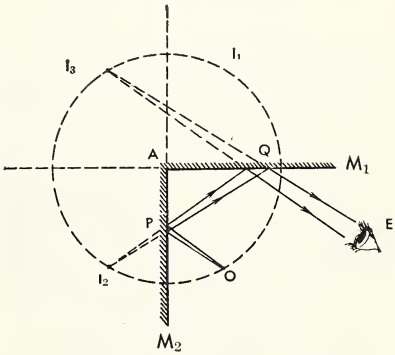


Fig. 17:8 Images in Mirrors at Right Angles.

images may be shown by a construction similar to that used previously.

3. Mirrors Inclined at Sixty Degrees

When mirrors are inclined, the number of images obtained depends upon the

angle between the mirrors. In general we can say:

the number of images

$$= \frac{360}{\angle \text{ Inclination}} - 1$$

For example, using mirrors at right angles we obtained three images

$$\left(\frac{360}{90} - 1 = 3\right).$$

If two mirrors are inclined at 60°, five images will be obtained (Fig. 17:9).

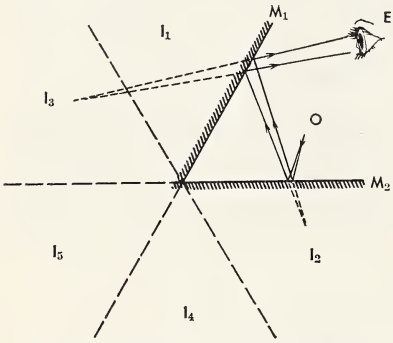


Fig. 17:9 Images in Mirrors Inclined at 60°.

Sir David Brewster, of Edinburgh, making use of the images produced by inclined mirrors, in 1819 invented the kaleidoscope. This consists of three mirrors set at angles of 60° to each other. These form multiple images of differently shaped pieces of coloured glass placed between them. Many beautiful and fascinating designs can be produced at every turn of the instrument.

IV : 14 CURVED MIRRORS

Curved mirrors are frequently more suitable than plane mirrors for certain purposes. Curved mirrors are used as rear-vision mirrors, as shaving mirrors and as reflectors for car headlights.

One important type of curved mirror is the **spherical mirror** whose reflecting surface is a portion of the surface of a sphere. If the inner surface is the reflecting surface, it is a **concave mirror**; if reflection occurs at the outer surface it is a **convex mirror**. We represent such mirrors in cross-section by the arc of a circle (Fig. 17:10).

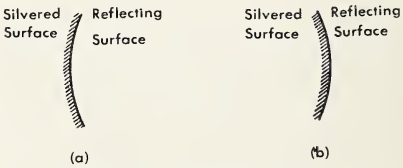


Fig. 17:10 Spherical Mirrors.
(a) Concave or Converging.
(b) Convex or Diverging.

A few terms used in connection with curved mirrors need to be defined (Fig. 17:11):

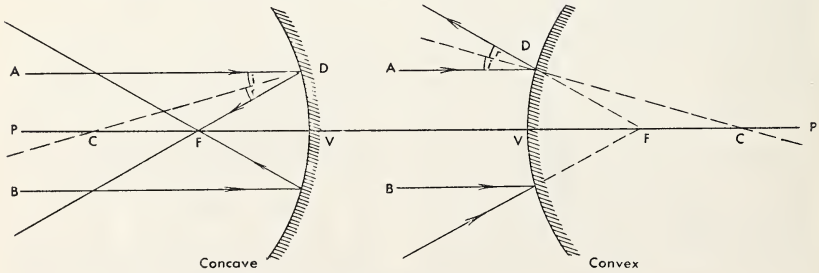


Fig. 17:11 Terms Used with Curved Mirrors.

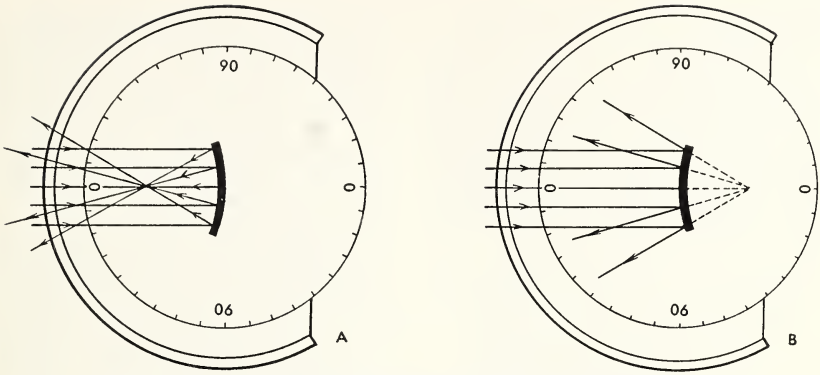


Fig. 17:12 Action of Curved Mirrors. (A) Concave. (B) Convex.

Centre of Curvature, *C*, is the centre of the imaginary sphere from which the mirror was cut.

Vertex, *V*, is the mid point of the mirror.

Principal Axis, *PV*, is the line through the centre of curvature and the vertex of the mirror.

Secondary Axis, *CD*, is any other line drawn through the centre of curvature to the mirror. Since all radii of a circle meet the circumference at right angles, and since all axes behave like radii since they pass through the centre of curvature, it follows, that a **Normal** to the surface of a curved mirror at the point of incidence is simply a secondary axis.

Principal Focus, *F*, is the point on the principal axis, through which rays, travelling parallel to the principal axis (and fairly close to it) pass, after being reflected from the mirror. For a convex mirror, the principal focus is a virtual focus, and is that point from which such rays appear to diverge after reflection from the mirror. This point will be found to be midway between the centre of curvature and the vertex of the mirror. There are many other foci possible, that is, points through which reflected light rays are converged. However, there is only one principal focus as defined.

Focal Length, *FV*, is the distance from the principal focus to the vertex of the mirror.

The action of curved mirrors (Chap. 21, Exp. 5), may be demonstrated by means of the optical disc. Mount a concave mirror on the optical disc so that the 0°—0° line becomes the principal axis of the mirror. Insert a metal shield with several parallel slits in the window of the opaque collar and shine light from a projection lantern through these slits onto the mirror (Fig. 17:12). You will note that the reflected rays converge. If the disc is rotated so that the incident rays are parallel to the principal axis it will be found that the reflected rays converge through a point. This point is the principal focus of the mirror. Similarly, if we insert a convex mirror in place of the concave one, and repeat the above, it will be found that the reflected rays diverge as though coming from a point behind the mirror. This virtual point locates the principal focus of the convex mirror.

IV : 15 IMAGES IN A CONCAVE MIRROR

In experiment 6, chapter 21 we studied the characteristics and position of images formed by a concave mirror for different positions of the object. As the object was moved closer to the mirror, the image, which was real and

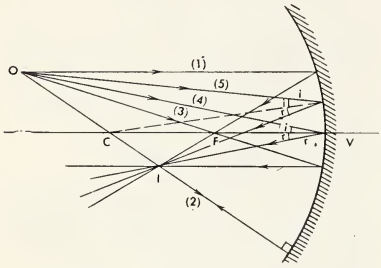


Fig. 17:13 Rays Used to Locate the Image, I, of an Object, O, in a Concave Mirror.

inverted, gradually grew larger in size and moved farther from the mirror. When the object was located inside the principal focus of the mirror, the image became virtual and erect and was located behind the mirror.

All of these results can be verified with fair accuracy by means of simple geometric diagrams. The principles used here are very similar to those used previously with plane mirrors. Each point on the object is sending out rays of light in straight lines in all directions. If we trace the paths of several of these rays from a point on the object, to the mirror, and then their reflected rays back from the mirror, we will find that they intersect. The point of intersection is the point on the image that corresponds to the original point on the object from whence the light rays came.

Suitable rays for this purpose, as illustrated in Fig. 17:13, are:

1. A ray from the object parallel to the principal axis, which will be reflected through the principal focus.
2. A ray from the object through the centre of curvature which will be reflected back along the same path, since the incident ray strikes the mirror at right angles.
3. A ray from the object through the principal focus, which will be reflected parallel to the principal axis.
4. A ray from the object to the vertex of the mirror, which will be reflected so that the angle of incidence equals the angle of reflection.
5. Any other ray from the object to the mirror will be reflected so that $\angle i = \angle r$.

In actual practice any two of these rays will suffice. The first two mentioned are the most easily drawn and hence are the most convenient to use.

In order to verify the observations obtained in our experiment, it is necessary to make accurate scale drawings.

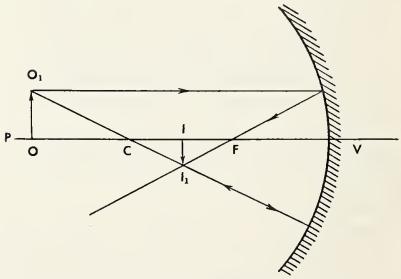


Fig. 17:14 To Locate the Image in a Concave Mirror of an Object Placed Beyond F.

For example, if the focal length of the concave mirror was 20 cm., the object 60 cm. from the mirror, and 12 cm. high, our construction would be as above (Fig. 17:14), using the scale 10 cm. = 1 cm.

Draw principal axis, PV. With centre C, and radius of curvature 4 cm. (twice focal length), draw an arc to represent the mirror. Locate the principal focus F, midway between C and V (2 cm. from mirror). Locate the object O, 6 cm. from the mirror. Draw the object (OO_1) 1.2 cm. high and perpendicular to the axis. From the tip of the object (O_1) draw the two rays and their reflected rays as outlined on previous page. These rays intersect at I_1, and hence locate the position of the tip of the image. (Rays from other points on the object would produce corresponding image points. However, the one is sufficient.) Draw the image II_1, perpendicular to PV. The distance of the image from the mirror and its size can be obtained by measuring accurately. Notice that when the object is beyond C, the image is between F and C, real, smaller than the object, and inverted. See how perfectly this diagram confirms your observations recorded in the table on page 242.

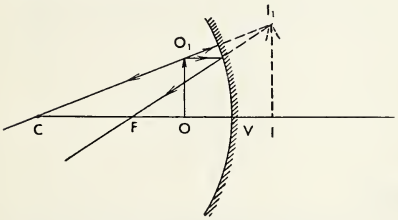


Fig. 17:15 To Locate the Image in a Concave Mirror of an Object Placed Between F and V.

The student should construct similar diagrams for other positions of the object, and verify the other observations made. The special case, where a virtual image is obtained, is slightly more difficult. Study the following diagram carefully, and note that the method is identical to that given previously (Fig. 17:15). However, this time the reflected rays diverge, and therefore appear to come from a point behind the mirror, thereby creating the virtual image.

IV : 16 IMAGES IN A CONVEX MIRROR

One has often observed the images produced by the back of a spoon, the side of a tea-kettle or the shiny fender of a car. Such objects as these are all acting as convex mirrors. In experiment

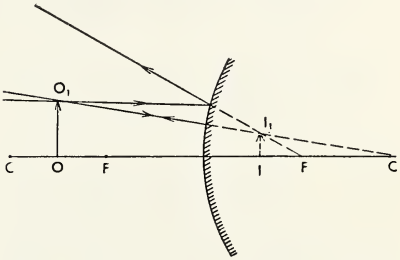


Fig. 17:16 To Locate the Image in a Convex Mirror.

7, chapter 21, we found that the images in a convex mirror were always behind the mirror, virtual, smaller than the object, and erect. The same method is used as with the concave mirror to verify this geometrically (Fig. 17:16).

IV : 17 HOW THE EYE SEES THE IMAGE

As previously discussed in section IV:12, the eye sees the image by means of rays which actually come from the object, but which appear to come from

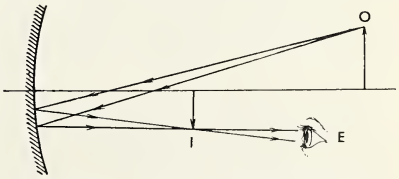


Fig. 17:17 How the Eye Sees a Real Image in a Concave Mirror.

the image. Fig. 17:17 and 17:18 show how this is accomplished. In each case the light rays start from the object, are reflected at the mirror, pass through a real image or appear to come from a

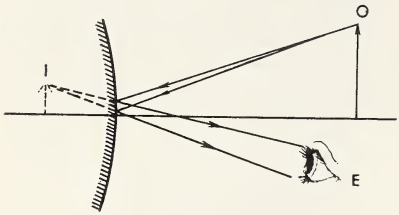


Fig. 17:18 How the Eye Sees a Virtual Image in a Convex Mirror.

virtual image, and enter the eye. In order to construct these diagrams just reverse the previous order. That is, join I to the outer edges of the pupil of the eye. This cone is projected back to the mirror or cuts the mirror. From there it is drawn back to the object.

IV : 18 THE MIRROR FORMULAE

In the previous sections we have been studying the images produced by curved mirrors. It is possible by means of two simple formulae to determine the location and characteristics of the image for various positions of the object. To do so, a consistent convention regarding signs must be followed. Values for distances of objects and real images are always positive; those for virtual images are negative. Similarly, the focal length of a concave mirror (which has a real principal focus) is positive, that of a convex mirror (with a virtual principal focus) is negative. To state this concisely, the convention of signs is:

"real is positive, virtual is negative"

The two formulae, with worked examples to show how to use them, follow:

(a) Magnification Formula

$$\frac{\text{Height of Image}}{\text{Height of Object}} = \frac{\text{Distance of Image}}{\text{Distance of Object}}$$

$$\frac{H_i}{H_o} = \frac{D_i}{D_o}$$

Note the similarity of this formula with that obtained for the pin-hole camera (Sec. IV:4).

(b) Distance Formula

$$\frac{1}{\text{Distance of Object}} + \frac{1}{\text{Distance of Image}} = \frac{1}{\text{Focal Length}}$$

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$$

Examples

1. An object 2 in. tall is placed 15 in. from a concave mirror whose focal length is 5 in. Find the position and size of the image.

$H_o = 2$ in.
$D_o = 15$ in.
$f = 5$ in.
$D_i = ?$

$$\because \frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$$

$$\therefore \frac{1}{15} + \frac{1}{D_i} = \frac{1}{5}$$

$$\therefore \frac{1}{D_i} = \frac{1}{5} - \frac{1}{15} = \frac{3-1}{15}$$

$$\therefore 2\,D_i = 15$$

$$\therefore D_i = 7.5$$

$\therefore$ The image is located 7.5 in. from the mirror.

$H_o = 2$ in.
$D_o = 15$ in.
$D_i = 7.5$ in.
$H_i = ?$

$$\therefore \frac{H_i}{H_o} = \frac{D_i}{D_o}$$

$$\therefore \frac{H_i}{2} = \frac{7.5}{15}$$

$$\therefore H_i = 1$$

$\therefore$ The image is 1 in. tall.

Check these results by making an accurate scale construction to locate the image geometrically. Both position and size of image should agree closely with the above values obtained by calculation.

2. An object 5 cm. high is placed 30 cm. from a convex mirror whose focal length is 20 cm. Find the position, size, and nature of the image.

$H_o = 5$ cm.
$D_o = 30$ cm.
$f = -20$ cm.
$D_i = ?$

$$\therefore \frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$$

$$\therefore \frac{1}{30} + \frac{1}{D_i} = \frac{1}{-20}$$

$$\therefore \frac{1}{D_i} = -\frac{1}{20} - \frac{1}{30}$$

$$= \frac{-3-2}{60}$$

$$\therefore -5\,D_i = 60$$

$$\therefore \quad D_i = -12 \text{ cm.}$$

$\therefore$ Image is 12 cm. from mirror and is virtual (since sign is negative).

$H_o = 5$ cm.
$D_o = 30$ cm.
$D_i = 12$ cm.
$H_i = ?$

$$\therefore \frac{H_i}{H_o} = \frac{D_i}{D_o}$$

$$\therefore \frac{H_i}{5} = \frac{12}{30}$$

$$\therefore H_i = 2 \text{ cm.}$$

$\therefore$ Image is 2 cm. high.

IV : 19 APPLICATIONS OF MIRRORS

Reference has already been made in section IV:11 to the uses of plane mirrors. Many of these uses, however, are more satisfactorily fulfilled by using curved mirrors. For example, a plane mirror is frequently used as a shaving mirror. However, a concave mirror so used produces an enlarged erect image when the face is held between the principal focus and the vertex of the mirror. The enlarged image is often a distinct advantage. Similarly, a convex mirror is frequently used as a rear vision mirror instead of a plane mirror. The erect, smaller image produced gives a wider field of view with the same size mirror.

Spherical mirrors such as we have been describing have one serious defect, known as **spherical aberration.** In such mirrors, only those rays parallel to the principal axis and fairly near to it pass through the principal focus on being

reflected from the mirror. Rays farther from the principal axis are reflected through points some distance from the focus (Fig. 17:19). Conversely, if a source of light is placed at the principal focus, the reflected rays will not form a parallel beam, but the outer ones will be scattered and hence the light is weakened.

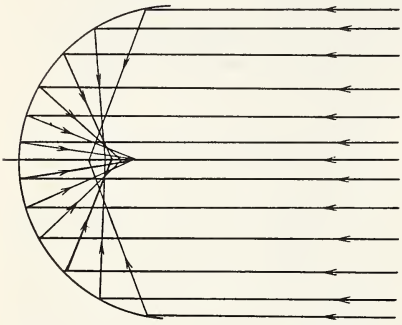


Fig. 17:19 Spherical Aberration in Curved Mirrors.

To overcome this defect, parabolic rather than spherical mirrors are used (Fig. 17:20). A **parabola** is a section from a cone obtained by cutting the cone

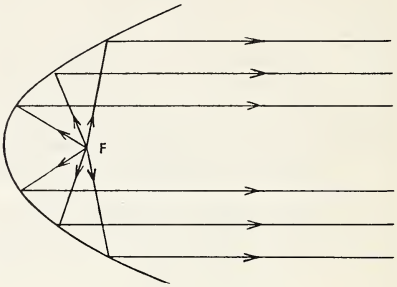


Fig. 17:20 A Parabolic Mirror Used to Prevent Spherical Aberration.

by a plane parallel to a line from the apex of the cone to any point on the circumference of the circular base. All rays which emanate from the principal focus of such a mirror, after reflection are parallel to the principal axis, no matter how great the aperture is. As a result parabolic mirrors are used as reflectors for searchlights, car headlights and in the reflecting telescope.

IV : 20 QUESTIONS

A

1. (a) Define: angle of incidence, angle of reflection.
   (b) State the two laws of reflection and indicate how you could test them.
2. (a) Distinguish between diffuse and regular reflection.
   (b) How is undesirable glare decreased?
3. (a) State the rule for determining the position of an image in a plane mirror.
   (b) Describe the image.
   (c) Distinguish between real and virtual images.
4. (a) Show by a diagram how you can locate the image of an inclined arrow in a plane mirror.
   (b) Show how an eye sees the image.
5. (a) How many images will be observed in 2 mirrors inclined at 45°?
   (b) Draw a diagram to locate these images.
6. (a) Define: principal axis, principal focus, focal length.
   (b) By means of accurate construction show how the principal focus of (i) a concave mirror, and (ii) a convex mirror may be located.
7. (a) Under what conditions does a concave mirror form (i) a real image, (ii) a virtual image?

(b) Describe the size and location of all the real images produced by a concave mirror.

(c) When a concave mirror is used in shaving, where is the person's face in relation to the principal focus of the mirror? What kind of image is seen?

8. An object is located just beyond the centre of curvature of a concave mirror.

(a) By means of a diagram locate its image.

(b) Show how the eye sees the image.

(c) State the characteristics of the image.

9. (a) State uses of plane, concave and convex mirrors.

(b) How does a searchlight produce a narrow beam of light?

B

1. A watch seen in a mirror seems to read (a) 2 o'clock, (b) 6.15 o'clock. What does it actually read? Explain.

2. Support a mirror vertically on a desk and stand a book in front of it to serve as a screen. Draw a triangle on a piece of paper and lay it flat between the book and the mirror. Watching the image in the mirror, but not the triangle itself, try to retrace the triangle. Why do you have difficulty?

3. What changes would you observe in your image as you walked toward (a) a plane mirror, (b) a concave mirror, (c) a convex mirror?

4. An object 15 cm. high is located (i) 75 cm. (ii) 60 cm. (iii) 45 cm. (iv) 30 cm. (v) 20 cm. from a concave mirror whose focal length is 30 cm.

(a) By means of accurate scale diagrams locate the position of the image for each position of the object.

(b) State the characteristics of each image.

5. By means of an accurate scale diagram locate the image produced by a convex mirror, whose focal length is 15 in., of an object 6 in. high and 2 ft. distant. State the characteristics of the image.

6. An object is 4 in. tall and its image is 6 in. tall when the object is placed 2 ft. from the mirror. How far is the image from the mirror?

7. A 6 in. pencil is 1 ft. in front of a curved mirror. Find the length of the image if it is 8 in. from the mirror.

8. How tall is an object if it produces an image 3 in. tall located 7 in. behind a convex mirror when the object is located 10 ft. in front of the mirror?

9. An object 4 in. in front of a concave mirror produces an image 12 in. behind the mirror. Find the focal length of the mirror.

10. An object is 18 cm. in front of a concave mirror which has a focal length of 12 cm. How far is the image from the mirror?

11. An object 9 in. from a convex mirror produces an image 3 in. behind the mirror. Find the focal length of the mirror.

12. An object is 15 cm. from a convex mirror of focal length 20 cm. Calculate the image distance.

13. The focal length of a concave mirror is 12 in. How tall is the image of a 5 in. candle standing 15 in. from the mirror?

14. Repeat question 13 using a convex instead of a concave mirror.

CHAPTER 18 REFRACTION OF LIGHT—LENSES

IV : 21 MEANING OF REFRACTION

Water frequently appears to be much shallower than it actually is. An oar or stick when only partly submerged appears to be bent upwards at the surface of the water (Fig. 18:1). These phenomena, and many others similar to them, are due to the bending of light rays as they pass obliquely from one medium into another of different optical

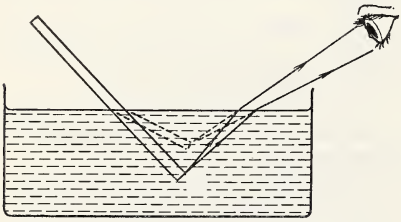


Fig. 18:1 Partly Immersed Stick Appears Bent.

density (Sec. IV:22). Such bending of the light rays is called **refraction.**

Refraction of light as it passes from air into water, or from water into air, can be illustrated easily. Fill a tank with water containing a small amount of fluorescein, or a little sodium thiosulphate (hypo) and a few drops of hydrochloric acid. These materials will render the water slightly turbid and make

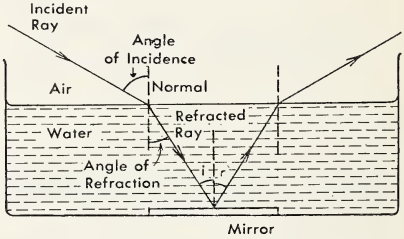


Fig. 18:2 Refraction of Light on Passing from Air to Water or from Water to Air.

visible a light beam projected through it. Shine a beam obliquely upon the surface of the water (Fig. 18:2). Part of this beam will be reflected at the surface of the water, and part will be refracted as it enters the water. If a normal (perpendicular) is placed at the point of incidence, it will be observed that the light beam is bent toward the normal. Similarly, if we shine the beam of light obliquely up through the water and into the air, it will be observed to bend away from the normal. Both effects can be shown simultaneously by placing a plane mirror on the bottom of the tank (Fig. 18:2). Note that no refraction occurs if the light enters or leaves the water at right angles to the surface.

We may also show that a beam of light is refracted on passing obliquely

from air into glass, or from glass into air. Place a semicircular block of glass on the optical disc, so that its flat edge is bisected at right angles by the $O°$–$O°$ axis of the optical disc. Shine a ray of light so that it strikes the surface at this central point where the axis crosses it. The axis thus is made the normal to the refracting surface. The light will

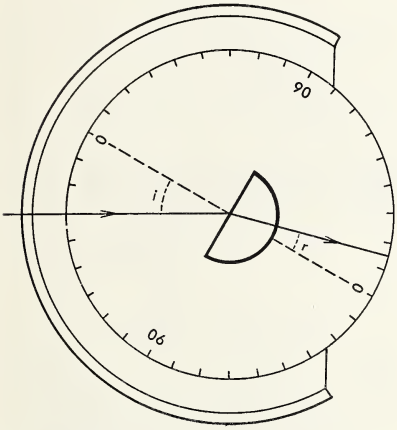


Fig. 18:3 Refraction of Light on Passing from Air to Glass.

be refracted as shown in Fig. 18:3. Why is the light not refracted on leaving, or on entering the circular surface of the glass?

From the preceding observations we may summarize the behaviour of light rays in passing from one medium into another of different optical density, as follows:

1. When a ray of light passes obliquely from one medium into another of greater optical density, it is refracted toward the normal.
2. When a ray of light passes obliquely from one medium into another of less optical density, it is refracted away from the normal.

It follows from the above that when a ray of light enters a new medium at right angles to the surface, no refraction occurs.

IV : 22 EXPLANATION OF REFRACTION

We may ask what causes refraction of light. The following illustration should help us to understand it. Suppose the brakes of an automobile are improperly adjusted, those on the right wheels holding better than those on the left. When the brakes are applied, the car will swerve to the right, that is, to the side that is slowed up most. Similarly, the bending of the light beam, or refraction, is caused by the change in the velocity of light as it passes from one medium into another of different optical density. The greater the optical density of a substance the more slowly light will travel through it.

According to the wave theory, light travels out from the source as spherical waves. When a wave-front enters an optically denser medium obliquely (Fig. 18:4), that part of it that enters the new medium first will be slowed, while the rest of it continues to advance at the same speed as before. Consequently, the wave-front swerves toward the normal as it enters the denser medium. Conversely, the wave-front would swerve away from the normal as it speeds up on passing into an optically less dense medium. No bending occurs if the light enters the new medium at right angles to the surface, for the entire wave-front would be slowed down or speeded up at the same instant.

IV : 23 INDEX OF REFRACTION

From Fig. 18:4 it is evident that the light is travelling the distance PR in one medium (air), while it travels the distance OQ in the other medium. Hence these distances must be proportional to

the velocities of the light in the two media. Also, it should be evident that the amount of refraction is governed by these

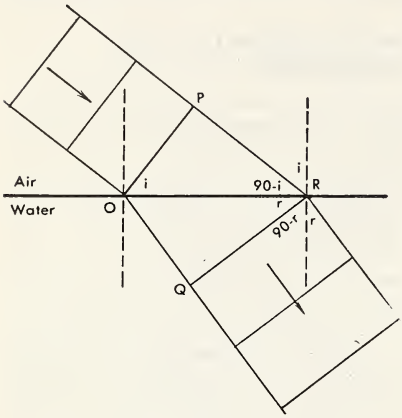


Fig. 18:4 Refraction of Wave Front on Entering an Optically Denser Medium.

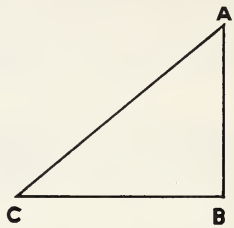
relative distances or these relative velocities, and would be constant for any two given media. This ratio is called the **index of refraction**, and may be defined as follows:

$$\text{Index of Refraction of a medium } (\mu) = \frac{\text{Velocity of light in air}}{\text{Velocity of light in the medium}} = \frac{V\ (\text{air})}{V\ (\text{medium})}$$

In experiment 8, chapter 21, by means of a simple geometric construction it is shown that

$$\text{Index of Refraction} = \frac{\text{Sine of angle of incidence*}}{\text{Sine of angle of refraction}}$$

The sine of an angle (abbreviated sin $\angle$) is a property of an angle found useful in calculations in mathematics and science. In the study of refraction only acute angles are involved. When the angle is contained in a right-angled triangle, its sine is a constant quantity found by dividing the length of the side opposite



the angle by the length of the hypotenuse. For example, in $\triangle$ ABC,

$$\text{Sin} \angle \text{ACB} = \frac{\text{AB}}{\text{AC}} \text{ and}$$

$$\text{Sin} \angle \text{CAB} = \frac{\text{BC}}{\text{AC}}$$

**To prove that:*

$$\textit{Index of Refraction } (\mu) = \frac{\textit{Sin} \angle i}{\textit{Sin} \angle r}$$

$$\mu = \frac{V\ (air)}{V\ (medium)} = \frac{PR}{OQ}$$

$$\frac{\textit{Sin} \angle i}{\textit{Sin} \angle r} = \frac{PR/OR}{OQ/OR} = \frac{PR}{OQ}$$

$$\therefore \mu = \frac{\textit{Sin} \angle i}{\textit{Sin} \angle r}$$

The index of refraction is an important physical property of a transparent medium. An instrument, called a refractometer is used to measure its value quickly and accurately. This enables scientists to identify substances and to check their purity. If the index of refraction of a substance is known the velocity of light may be determined for that substance. A substance with a large index of refraction is said to have a

high optical density, because it permits light to travel through it at a relatively slow velocity. Such substances refract light to a greater extent than do those with a smaller index of refraction. The brilliance of diamonds, and other precious stones is largely due to this fact (Sec. IV:26). The index of refraction of a substance varies with the colour of the light that passes through it. The rainbow and the beautiful colours obtained when light is refracted through cut glass and precious stones are due to this (Sec. IV:37). Temperature, too, has an effect on the index of refraction because it alters the optical density of a substance. The waviness observed when light passes through air rising above a hot object is caused by the differing refractive indices of various layers of hot and cold air.

THE INDEX OF REFRACTION OF SOME COMMON SUBSTANCES

Water	1.3	Quartz	1.5
Crown Glass	1.5	Zircon	1.9
Flint Glass	1.7	Diamond	2.4

IV : 24 REFRACTION THROUGH A GLASS PLATE

When a ray of light passes obliquely through a glass plate with parallel sides (Chap. 21, Exp. 9), it is refracted both on entering and on leaving the glass. On entering, the light is slowed down and is, therefore, refracted toward the normal. On emerging, the light speeds up again, and hence is refracted away from the normal. Since this second effect exactly counteracts the first (i.e., the speeding up exactly compensates for the original slowing down), the emergent ray will be parallel to the incident ray but laterally displaced (Fig. 18:5). The amount of this lateral displacement depends on the refractive index of the glass, on the angle of incidence, and on the thickness of the glass. On looking at an object through such a plate, it will be slightly displaced in position and will appear nearer to the eye than it is in fact (Fig. 18:6). The same thing occurs in water and this accounts for the difficulty in locating the exact position of an immersed object (Chap. 21, Exp. 10).

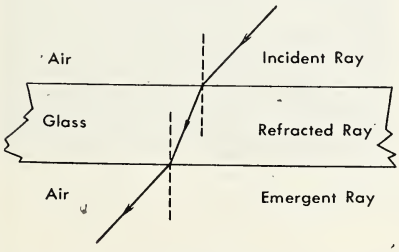


Fig. 18:5 Refraction Through a Glass Plate with Parallel Sides.

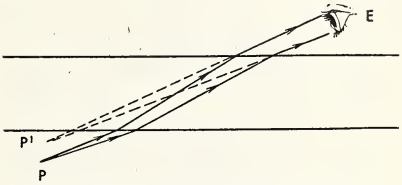


Fig. 18:6 Why an Object Appears Closer When Viewed Through a Glass Plate.

IV : 25 REFRACTION THROUGH PRISMS

A **prism** consists of a wedge-shaped portion of a refracting substance, bounded by two plane surfaces inclined at an angle to each other, this angle being called the refracting angle. When a ray of light enters such a prism it is slowed down, and therefore refracted toward the normal. On leaving, it speeds up, and therefore bends away from the normal. This can be shown by mounting a 60° prism on an optical disc and shining a ray of monochromatic light, e.g., red, through it. From Fig. 18:7 it is seen

that both these refractions are toward the thick base of the prism. Hence the light is bent, or deviated, quite considerably from its original path. The angle of deviation, D, is obtained by extending the incident and emergent rays to meet (Chap. 21, Exp. 11).

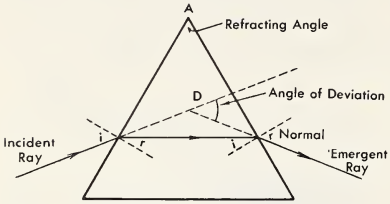


Fig. 18:7 Deviation Through a Glass Prism.

The amount of deviation produced by a prism depends upon a number of factors. First, the material comprising the prism—the greater its index of refraction, the greater will be the deviation produced. Secondly, the shape of the prism—the greater its refracting angle, the greater will be the angle of deviation. Thirdly, the angle of incidence at which the light meets the prism. This can be shown by rotating the optical disc and observing the amount of deviation for various angles of incidence. Minimum deviation is obtained from an equilateral prism when the refracted ray passes through the prism parallel to the base. Finally, the amount of deviation depends upon the colour, or the wavelength, of the light used, which is why monochromatic light was used in these experiments. This latter factor gives prisms one of their large areas of usefulness. More discussion on this follows in the chapter on colour, page 213.

IV : 26 TOTAL REFLECTION

It is more usual to consider light passing from air into an optically denser medium; however, when it goes from the optically denser medium into air, or a less dense medium such as from water or glass into air, a peculiar phenomenon occurs. As the light speeds up on entering the air obliquely it bends away from the normal. As the angle of incidence in the denser medium increases, we finally come to a position when the refracted ray just grazes the surface, that is, the angle of refraction equals 90°. This angle of incidence is called the **critical angle.** When the incident angle exceeds the critical angle the light is completely reflected, a phenomenon known as **total reflection** (Fig. 18:8). Using the semicircular block of glass on the optical disc as in section IV:21, shine a ray of light through it. Rotate the disc to increase the angle of

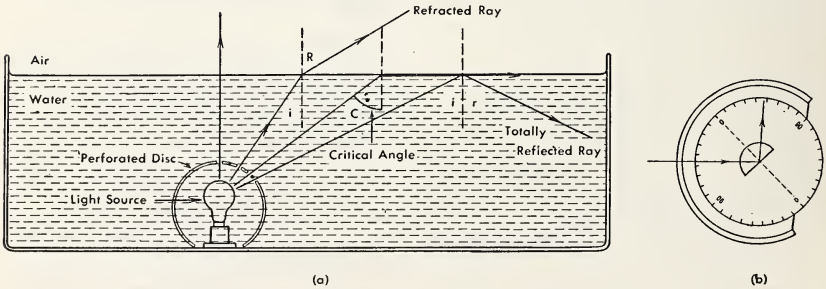


Fig. 18:8 Total Reflection of Light (a) On Passing from Water to Air. (b) On Passing from Glass to Air.

incidence and note the size when total reflection first occurs. This angle, the critical angle for glass, is about 42°.

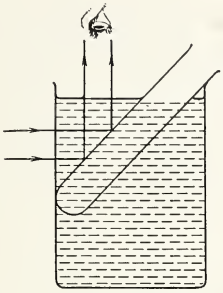


Fig. 18:9 An Illustration of Total Reflection.

An example of total reflection is seen when an empty test-tube is placed in a

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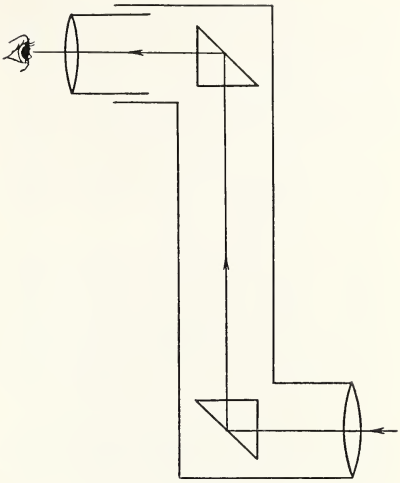
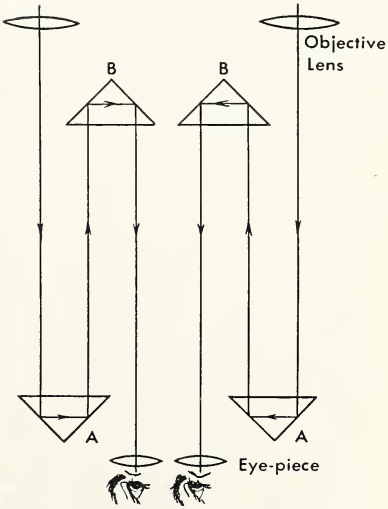
An Interesting Example of Light Being "Bent" in a "Perspex" Rod.

beaker of water (Fig. 18:9). On looking down into the water the sides of



(a)



(b)

Fig. 18:10 Applications of Total Reflection Prisms (a) A Simple Periscope. (b) Field Glasses.

the test-tube appear silvery. This is due to the light striking the surface of the tube at an angle greater than the critical angle for glass. This light is totally reflected to the eye as shown. Similarly a sooted ball appears silvery on being lowered into a beaker of water. A layer of air entrapped by the coating of soot produces a water-air boundary at which reflection occurs.

Total reflection is a very useful phenomenon. Total reflection prisms are usually right-angled prisms with well-polished faces. Light enters such a prism at an angle of incidence of 45°, which is greater than the critical angle for glass (p. 201), and hence total reflection occurs. Such prisms are used in periscopes (Fig. 18:10a), range finders, field-glasses (Fig. 18:10b), and reflecting telescopes. They are much more efficient reflectors than mirrors, since mirrors reflect only about seventy per cent of the light they receive, whereas prisms reflect a much greater proportion. In addition, prisms are more robust, there is no silvering to tarnish and they give rise to a single well-defined image.

The brilliancy of diamonds, brilliants, and cut-glass dishes is due to total reflection. The greater the index of refraction of a substance the smaller is its critical angle. Diamonds have a large index of refraction (Sec. IV:23) and consequently have a small critical angle. The surfaces of the diamonds meet each other at such angles that much of the light entering a diamond is totally reflected a number of times internally, before eventually being refracted out. This lights up many surfaces, and gives the diamond its sparkle. Brilliants, and cut-glass articles are often made of leaded glass. The addition of lead increases the index of refraction, and consequently the cut faces are able to cause much total reflection.

IV : 27 ATMOSPHERIC REFRACTION

Light travels faster in a vacuum than in air. Therefore, light reaching us from the sun and stars will slow up and be refracted as it enters the atmosphere of the earth. Since the atmosphere gradually becomes denser as the altitude decreases, the light will be refracted more and more as it passes through successive layers of denser air nearer the surface. Consequently, when light comes to us obliquely from the sun and stars these

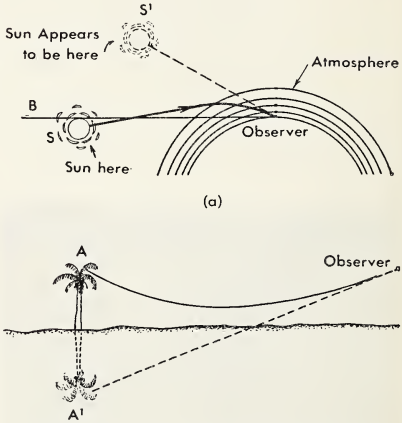


Fig. 18:11 Atmospheric Refraction
(a) The Sun Low on the Horizon.
(b) A Mirage.

bright objects appear higher than they really are (Fig. 18:11a). This effect is most pronounced at low altitudes because of the larger angles of incidence, and the increased distances to be travelled through the successive layers of air. As a result the sun appears to set several minutes after it has actually passed below the horizon. The enlarged and sometimes elliptical appearance of the sun and moon when near the horizon is due to the fact that rays from the

lower edge are refracted more than those from the upper edge.

A mirage is a well-known optical illusion caused by refraction and sometimes total reflection of light as it passes through layers of atmosphere of varying density (Fig. 18:11b). Objects in the distance may be raised above or depressed below their normal position and may be distorted into irregular fantastic shapes. The most commonly observed mirage is that of an apparent layer of water over a hot level sandy surface, or paved roadway. The mirage in these cases is really an image of the sky, produced by total reflection from layers of air near the ground.

IV : 28 LENSES

A **lens** is a piece of transparent refracting medium, usually glass, bounded by two spherical surfaces, or by a plane and a spherical surface.

There are two main types:

(a) **Converging or Convex Lenses** are thicker at the centre than at the outer edge. Such lenses always refract rays of light so as to converge them. They therefore collect light.

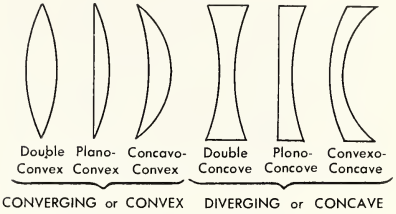


Fig. 18:12 Kinds of Lenses.

(b) **Diverging or Concave Lenses** are thinner at the centre than at the outer edge. These lenses cause light rays to diverge. They therefore scatter light.

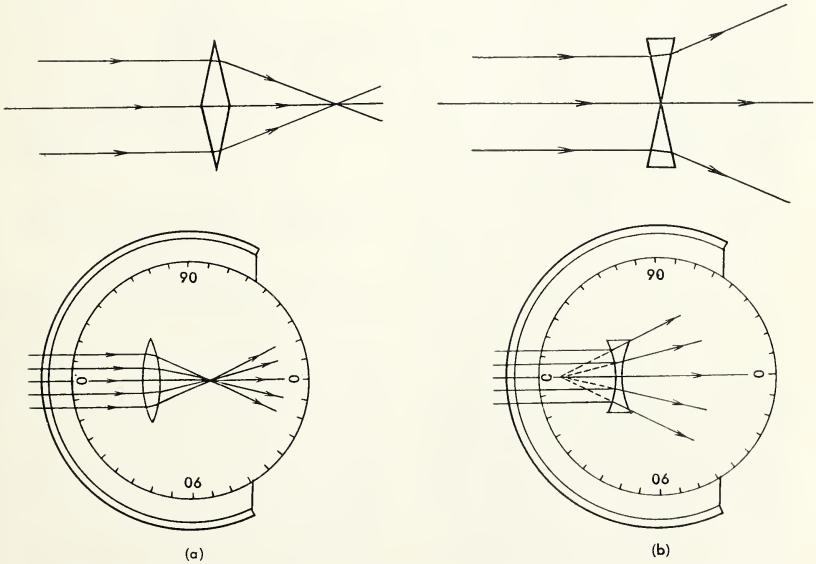


Fig. 18:13 Comparison of Lenses and Prisms. (a) Action of a Converging Lens. (b) Action of a Diverging Lens.

These two types of lenses may be of varying shapes as shown in Fig. 18:12. Each shape is devised for a specific purpose.

The action of a lens is similar to that of two prisms base to base (Fig. 18:13). As discussed in section IV:25, the light is bent toward the base of the prism both on entering and leaving the prism. Similarly, the light is bent toward the thicker part of the lens both on entering and leaving it. These examples explain the converging action of a convex lens, and the diverging action of a concave lens.

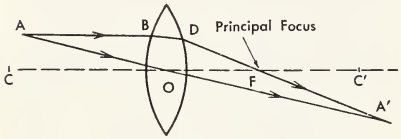


Fig. 18:14 Terms Pertaining to Lenses.

The study of lenses makes use of a new vocabulary. The terms used are explained below (Fig. 18:14):

Centre of Curvature C, C^1: In most lenses there are two centres of curvature. They are the centres of the spherical surfaces that bound the lens.

Principal Axis of a lens is the line passing through the centres of curvature of the two faces, or, in the case of a lens which has one face plane, it is the line passing through the centre of curvature of the curved face and which is normal to the plane face.

Optical Centre O, is the point on the principal axis midway between the two surfaces of the lens. All distances along the principal axis are measured from this point.

Principal Focus F, of a convex lens is that point on the principal axis to which a beam of light which is parallel to the principal axis converges after refraction through the lens. (In a concave lens, the principal focus is a virtual point, and is that point on the principal axis from which a beam of light, which is parallel to the principal axis, appears to diverge on being refracted through the lens.)

Focal Plane is a surface that passes through the principal focus perpendicular to the principal axis of the lens.

Focal Length is the distance of the principal focus from the optical centre of the lens.

Note 1: In Fig. 18:15 (see below) a line has been drawn through the optical centre of the lens perpendicular to the principal axis. For simplicity, we may represent the entire refraction of light as occurring at this line. Actually, of course, a light ray will be refracted both

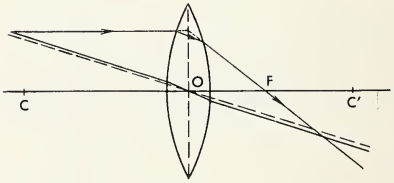


Fig. 18:15 Represented and Actual Paths of Light Through a Lens.

on entering and on leaving the lens. This actual path of the light through the lens is shown by drawing a line between the point where the incident ray enters the lens, and the point where the refracted ray leaves the lens.

Note 2: A ray through the optical centre of a lens may be considered as passing straight through the lens. This is because the surfaces of the lens through which the light is travelling are almost parallel. Therefore, the light will be refracted on entering and on leaving

in such a way that the emergent ray will be parallel to, but laterally displaced from, the incident ray (Sec. IV:24). We shall consider all our lenses to be very thin, so that the amount of lateral displacement is negligible.

IV : 29 FOCAL LENGTH OF LENSES

To determine the focal length of a lens the position of the principal focus

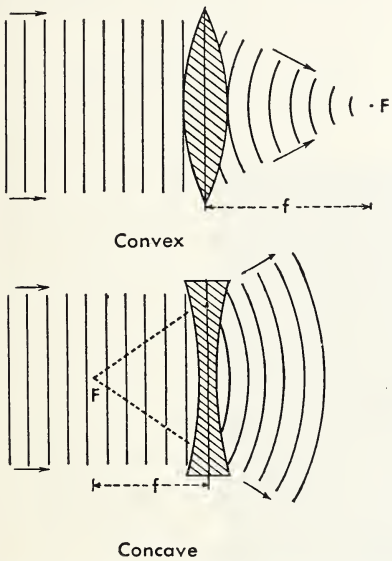


Fig. 18:16 Principal Focus of a Convex Lens and a Concave Lens

must first be determined and then its distance from the optical centre of the lens measured (Chap. 21, Exp. 12). This may be demonstrated by placing a convex lens on an optical disc. Shine a number of rays, parallel to the principal axis, through the disc and note the point through which they converge. This point is the principal focus (Fig. 18:16). The focal length depends upon the index of refraction of the lens and its thickness. Increasing either or both of these increases the amount of bending of the light and so shortens the focal length. The powers of lenses used in most optical instruments are usually expressed in terms of their focal lengths.

In optometry it is more usual to deal with the power of a lens rather than its focal length. The unit of power is the **dioptre**, which is the power of a converging lens of focal length one metre (100 centimetres). The shorter the focal length, the greater the power of the lens, and accordingly the power can be related to the focal length by the formula:

$$P\ (\text{dioptres}) = \frac{100}{f\ (\text{cm.})}$$

According to our convention of signs (Sec. IV:18, and IV:32), a convex lens with a real principal focus has a positive focal length and a + power; a concave lens with a virtual principal focus has a negative focal length and a — power.

If a lens is used in a different medium, its focal length and therefore its power will change. This can be shown by placing a lens in a tank of turbid water (Fig. 18:17). Shine a parallel beam of

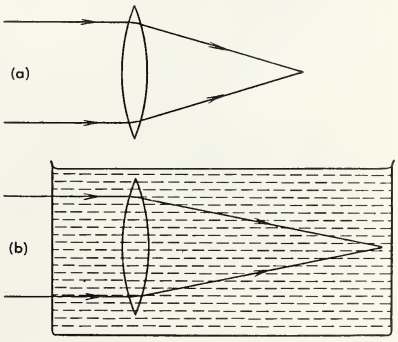


Fig. 18:17 Comparison of Focal Lengths of Lens (a) In Air (b) Immersed in Water.

light through the water and the lens, and compare the focal length in water with that previously obtained in air. It will be found to be longer. This is to be expected as there is a smaller decrease in velocity of the light going from water to glass than when going from air to glass. Consequently there is less bending of the light, and therefore a longer focal length. A convex air lens in water would function as a diverging lens. Explain why. It can be constructed by cementing watch glasses together using a waterproof cement.

Care should be observed in the use and location of spherical transparent objects. For example, a glass globe of water in sunlight could focus the sun's rays. If flammable material should be located at the principal focus of this lens a fire could easily result. Use is made of this very fact in some types of sunlight recorders used by weather bureaus.

A sunlight recorder is a device used to determine the number of hours of bright sunshine. In Ontario, the meteorological department uses the Campbell-Stokes Sunshine Recorder (Fig. 18:18). It consists essentially of two parts:

(1) A glass sphere which brings the sun's rays to a focus.

(2) An approximately spherical metal

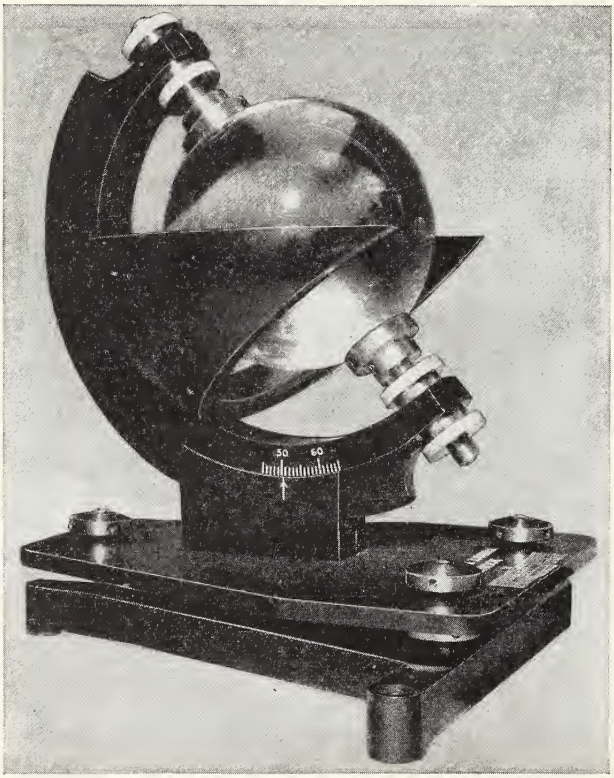


Fig. 18:18

A Sunlight Recorder.

bowl carries cards which form a belt on which the sun burns a record.

Real care must be observed in setting up the recorder. There must be no obstructions that would shield the recorder from the sun's rays. It must be placed on a rigid table, and made perfectly level. Instructions are always provided for adjusting for latitude, and for adjusting for the time meridian. The glass ball must be kept perfectly clean at all times.

IV : 30 IMAGES IN CONVEX LENSES

Previously we saw how images were formed in concave mirrors (Sec. IV: 15). Convex lenses form a very similar series of images by refracting the light that passes through them. In experiment 13, chapter 21 the method of studying the characteristics and position of the images formed is given. It will be found that as the object approaches the lens up to the focal plane the image formed on the opposite side of the lens is real, inverted, and gradually becomes larger in size as it moves farther from the lens. When the object is located inside the focal plane, the image becomes virtual, erect, and is located on the same side of the lens as the object.

As in mirrors, so in lenses, it is possible to verify these results by means of simple geometric diagrams. To do so it is necessary to draw two rays from any point on the object, and determine through what point they are focused by the lens (Fig. 18:19). The two most suitable rays are:

(1) A ray from the tip of the object parallel to the principal axis. This ray on passing through the lens is refracted through the principal focus.

(2) A ray from the tip of the object through the optical centre of the lens. This ray may be considered as passing straight through the lens (Sec. IV:28).

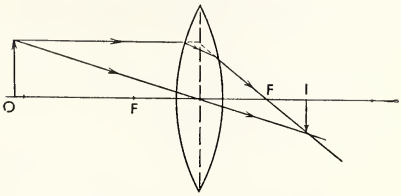


Fig. 18:19 To Locate a Real Image in a Convex Lens.

The point where these two refracted rays cross locates the tip of the image. A similar construction for other points on the object will locate the corresponding points on the image.

Fig. 18:20 shows how to locate the virtual image obtained when the object is inside the focal plane of the lens.

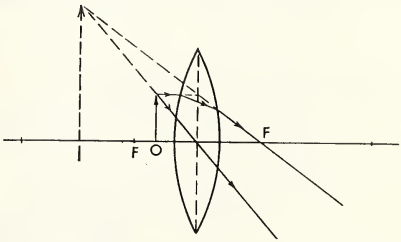


Fig. 18:20 To Locate a Virtual Image in a Convex Lens.

The construction is identical to that just described. Because the refracted rays diverge from each other, it is necessary to produce them back to where they appear to meet.

IV : 31 IMAGES IN CONCAVE LENSES

By referring to experiment 14 chapter 21 it will be observed that concave lenses can form virtual images only. These are

always erect, smaller than the object, and located at less than the focal distance from the lens (Fig. 18:21). A close similarity will be noted between the images formed by concave lenses and those formed by convex mirrors (Sec. IV:16).

Fig. 18:22 shows how the eye sees the image produced by a lens.

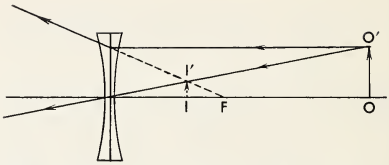


Fig. 18:21 To Locate the Image of an Object in a Concave Lens.

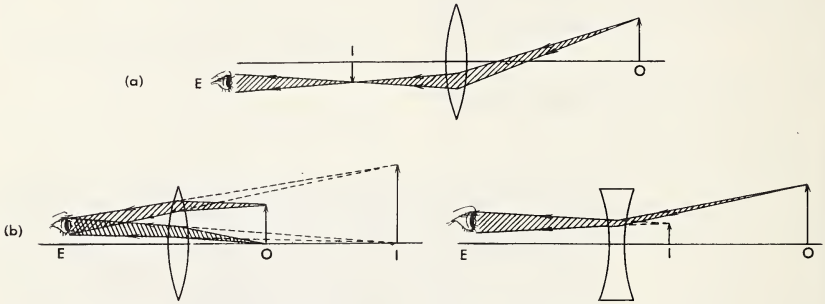


Fig. 18:22 How the Eye Sees the Image Produced by a Lens. (a) Real Images. (b) Virtual Images.

IV : 32 THE LENS FORMULAE

The formulae we obtained for curved mirrors (Sec. IV:18) also apply to lenses, that is,

(a) Magnification Formula

$$\frac{\text{Height of Image}}{\text{Height of Object}} = \frac{\text{Distance of Image}}{\text{Distance of Object}}$$

$$\frac{H_i}{H_o} = \frac{D_i}{D_o}$$

(b) Distance Formula

$$\frac{1}{\text{Distance of Object}} + \frac{1}{\text{Distance of Image}} = \frac{1}{\text{Focal Length}}$$

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$$

The same convention of signs must be followed, namely: real is positive, virtual is negative.

Examples

1. An object 5 cm. tall is placed 30 cm. from a convex lens whose focal length is 10 cm.

(a) By means of an accurate scale diagram locate the image, and state its characteristics.

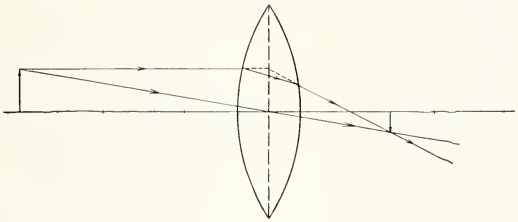


Fig. 18:23 Scale 5 cm. = ¼ in.

(b) By using the lens formulae, determine the position of the image, and its size. How could you tell from your answer whether it is real or virtual?

$D_o = 30$ cm.
$f = 10$ cm.
$D_i = ?$

$$\because \frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$$

$$\therefore \frac{1}{30} + \frac{1}{D_i} = \frac{1}{10}$$

$$\therefore \frac{1}{D_i} = \frac{1}{10} - \frac{1}{30}$$

$$= \frac{3-1}{30}$$

$$\therefore D_i = 15$$

$\therefore$ Image distance is 15 cm.

Note: Since the image distance is + 15 cm., therefore the image is real.

$D_o = 30$ cm.
$D_i = 15$ cm.
$H_o = 5$ cm.
$H_i = ?$

$$\because \frac{H_i}{H_o} = \frac{D_i}{D_o}$$

$$\therefore \frac{H_i}{5} = \frac{15}{30}$$

$$\therefore H_i = 2.5$$

$\therefore$ Height of image is 2.5 cm.

2. A concave lens has a focal length of 4 in. An object 1 in. high is 12 in. from the lens.

(a) Determine the position and size of the image.

(b) Verify your answer by making an accurate scale diagram.

$f = -4$ in. (— since f is virtual)
$D_o =$ 12 in.
$H_o =$ 1 in.

$$\because \frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$$

$$\therefore \frac{1}{12} + \frac{1}{D_i} = -\frac{1}{4}$$

$$\therefore \frac{1}{D_i} = -\frac{1}{4} - \frac{1}{12}$$

$$= \frac{-3-1}{12}$$

$$\therefore D_i = -3$$

$\therefore$ Image distance is 3 in.

Note: Since the image distance is negative, therefore, the image is virtual.

$H_i =$?
$H_o = 1$ in.
$D_i = 3$ in.
$D_o = 12$ in.

$$\because \frac{H_i}{H_o} = \frac{D_i}{D_o}$$

$$\therefore \frac{H_i}{1} = \frac{3}{12}$$

$$\therefore H_i = .25$$

$\therefore$ Height of image is .25 in.

IV : 33 APPLICATIONS OF LENSES

As lenses are an essential part of almost every optical instrument, a discussion of their major applications is reserved until chapter 20 where several optical instruments are described. However, to relate specifically to the facts learned in the preceding sections we will mention a few simple uses here. The camera (Sec. IV:44), the eye (Sec. IV:45), the telescope (Sec. IV:48) and the projection lantern (Sec. IV:49) all contain a convex lens as an essential part of their construction. All these instruments produce real, inverted images because the object viewed in each case is beyond the principal focus of the lens. In the magnifying glass (Sec. IV:46) and microscope (Sec. IV:47) an enlarged, erect, virtual image is obtained because the object is inside the principal focus of the convex lens. Concave lenses are used along with convex lenses in many optical instruments to overcome certain defects, e.g., chromatic aberration (Sec. IV:42), that would be apparent if the convex lens were used alone.

IV : 34

QUESTIONS

A

1. (a) Define refraction of light.
(b) Describe and explain the refraction of light as it passes obliquely from one medium into another of different optical density.

2. (a) Define index of refraction.
(b) Draw a diagram showing how you can see a coin lying on the bottom of a dish filled with water, though the coin would be hidden if the dish contained no water.
(c) What is the velocity of light in quartz? (See table p. 199 for index of refraction of quartz).
(d) The velocity of light in a diamond is 75,300 miles per second. What is its index of refraction?

3. (a) How do you account for the shimmering effect seen in the air above a hot radiator?
(b) How does the same principle account for the twinkling of the stars?

4. Place a thick glass plate on a line drawn on a piece of paper. View the line obliquely. Describe and explain what is observed.

5. (a) With the aid of a diagram explain why an oar appears bent when partly immersed in water and viewed obliquely.
(b) Is the index of refraction greater for glass in which the velocity of light is 124,000 miles per second, or for water, in which the velocity is 140,000 miles per second? Why?

6. (a) Define angle of deviation.
(b) State four factors that govern the amount of deviation produced by a prism.
(c) Is the index of refraction of glass constant for all colours of light? Explain your answer.

7. (a) Define critical angle. Illustrate your definition with a labelled diagram.
(b) Would the critical angle be greater for water (index of refraction 1.33) or for glass (index of refraction 1.5)? Why?

8. (a) Draw a diagram to show how a right-angled prism may be used to secure (i) one total internal reflection, (ii) two total internal reflections.
(b) Explain why total reflection occurs in these two cases.
(c) Why are total-reflection prisms preferable to mirrors in many optical instruments?

9. (a) Compare the action of lenses to that of two prisms.
(b) Define principal focus of a lens.
(c) How can you determine experimentally the focal length of a lens?
(d) Calculate the power of a lens whose focal length is 0.15 metres.

10. (a) What is the purpose of a sunlight recorder?
(b) What approximate position relative to the glass sphere should the recording-belt occupy in the sunlight recorder?

11. (a) Distinguish between convex and concave lenses.
(b) Summarize the types of images possible with both types of lenses and the conditions under which each is obtained.

12. An object is located at a point more than twice the focal length from a convex lens.
(a) By means of a diagram locate its image.
(b) State the characteristics of the image.

13. (a) What do we mean by the magnification produced by a lens?

(b) How does the magnification depend on image distance and object distance?

B

1. What is the index of refraction of a liquid in which the speed of light is 155,000 miles per second?

2. The index of refraction of diamond is 2.47; that of window glass is 1.51. How much faster does light travel in the glass than in diamond?

3. Light strikes the surface of glass making an angle of incidence of (a) 60°, (b) 45°, (c) 30°. The index of refraction of glass is 1.5. By means of accurate geometric diagrams draw the refracted ray for each case. Using a protractor, measure the angles of refraction.

4. By means of an accurate construction determine the size of the angle of incidence when the angle of deviation is a minimum in an equilateral crown-glass prism. Measure the angle of deviation.

5. In which material does light travel faster, one with a critical angle of 25° or one with a critical angle of 30°? Explain, using appropriate diagrams.

6. An object 15 cm. high is located (i) 75 cm. (ii) 60 cm. (iii) 45 cm. (iv) 30 cm. (v) 20 cm. from a convex lens whose focal length is 30 cm.

(a) By means of accurate scale diagrams locate the position of the image for each position of the object.
(b) State the characteristics of each image.

7. By means of an accurate scale diagram locate the image produced by a concave lens whose focal length is 15 in. of an object 6 in. high and 2 ft. distant. State the characteristics of the image.

8. A camera forms an image 8 cm. from the lens. If the object is 400 cm. away and 250 cm. tall, what is the height of the image?

9. The image of a tree in a miniature camera is 50 mm. from the lens and 30 mm. high. The tree is 15 metres away. How tall is the tree?

10. The image of an object 3 in. from a lens is formed 20 ft. from the lens. How many times is it magnified?

11. The image of an object 24 ft. from a lens is focused clearly on a screen 3 ft. from the lens. What is the focal length of the lens?

12. A convex lens forms a virtual image at a point 12 cm. from the lens. The object distance is 8 cm. Find the focal length of the lens.

13. A tree 100 ft. from a camera lens has its image very close to the principal focus of the lens. If the tree is 66 ft. tall and the image is 4 in. tall, what is the focal length of the lens?

14. A candle is 12 cm. from a convex lens of focal length 8 cm. What is the distance from the lens to the image of the candle?

15. A student uses a convex lens to look at an object held 4 cm. from the lens. If the focal length of the lens is 5 cm., how far is the image from the lens? What kind of image is it?

16. The image in a camera is 10 cm. high and 14 cm. from the lens. If the object is 100 cm. tall, what is the focal length of the lens?

17. A jeweller uses a converging lens of focal length 1 in. to examine a diamond. The virtual image is 10 in. from the lens. Find (a) the object distance, (b) the magnification.

18. When photographing a scene at a distance of 6 ft. from the lens, you find that the distance between the lens and the film is 6 in.

(a) What is the focal length of the lens?
(b) What is the actual size of a portion of a scene which occupies a space 3 in. × 5 in. on the film?

CHAPTER 19 COLOUR

IV : 35 INTRODUCTION TO COLOUR

Imagine how drab and uninteresting the world would be if there were no colour. Think of the pleasure and stimulation we receive from the colours of nature—the blue sky, the green grass, the beautiful flowers, the gorgeous hues of the sunrise and sunset. The use of colour in photography, in movies, and in book illustrations has added tremendously to our enjoyment of these things. How appealing and satisfying are some of the beautifully coloured masterpieces of art! Economically too, colour plays a very important role, as shown by the varied colours used in home decorating, clothing, advertising, and the like.

For thousands of years men have known that colourless glass of certain shapes, as well as frost, diamonds and other crystals, produce light of many colours when illuminated by white light. Until the time of Sir Isaac Newton everyone supposed that the glass or crystals produced the light by giving something to the light as it was reflected by, or transmitted through, them. It was he who, after thorough scientific investigation arrived at the true explanation of the nature of colour and the character of white light.

IV : 36 COMPOSITION OF WHITE LIGHT

(a) Dispersion

In 1666, Newton permitted a beam of sunlight, passing through a circular hole in a window blind, to fall on a triangular glass prism. He found that the light was refracted or deviated, from its original path. Instead of obtaining a simple image of the hole, he obtained a band of colours which he called a **spectrum.** Its colours were the same as those found in the rainbow—red, orange, yellow, green, blue and violet, with each colour merging imperceptibly into the next (Fig. 19:1). Newton reasoned that white light must be composite, that is, made up of a combination of the above colours. The separation of the colours by the prism he called **dispersion.** A further study of dispersion is made in experiment 15, chapter 21.

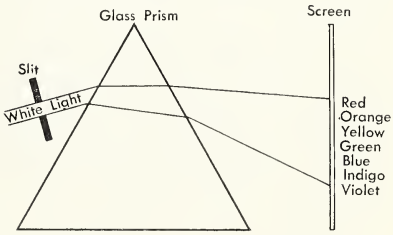


Fig. 19:1 Dispersion of White Light into its Spectrum.

As shown in Fig. 19:1 this dispersion occurs because the different colours are refracted different amounts by the prism and are deviated different amounts from their original direction. Red is always bent the least from its original direction and violet the most, with the other colours intermediate between these.

As we learned earlier (Sec. IV:22), refraction is caused by a change in velocity of light on passing from one medium to another. In free space, or in air, light of all colours travels at the same rate, 186,000 miles per second. On entering an optically denser medium such as glass the light is slowed down, and on leaving this medium it speeds up to regain its original velocity in air. Since the different colours are bent different amounts by the prism, it follows that they must be travelling at different velocities through the prism. Red light, bent the least, must slow down the least on entering the prism and therefore speeds up the least on leaving. In contrast, violet light must slow down the most on entering, and speed up the most on leaving the prism.

A question that immediately arises of course is, "Why does the prism have this different effect on the different colours?" The answer relates back to our wave theory of light (Sec. IV:7). The different colours of light result from different wave-lengths.

Red light has the longest waves and violet the shortest, the wave-lengths of the other colours being between these two. Evidently, the longer red rays encounter less opposition to their passage through the glass prism and, therefore pass through more rapidly than do the violet rays.

TABLE OF WAVE-LENGTHS*

(1 Angstrom (Å) $= 10^{-8}$ cm.

Infra-red above 7000 Å		
Red	6500Å	Visible Spectrum
Orange	6000Å	
Yellow	5800Å	
Green	5200Å	
Blue	4700Å	
Violet	4100Å	
Ultra-violet below 4000 Å		

* The wave-length shown for each colour is representative only. Each colour consists of wave-lengths that merge into those of the colours adjacent to it. For example, the wave-lengths of red lie between 6470 Å and 7000 Å.

Colour bears the same relation to light that pitch does to sound. The pitch of a sound depends upon the number of vibrations per second that reach the ear (Sec. II:12). Similarly the colour of light depends upon the number of vibrations per second that reach the eye. In light, however, since the frequency is so great, it is customary to describe the colour in terms of wave-lengths, rather than in terms of vibration frequency.

Example

Calculate the vibration frequency of red light.

Velocity $= 3 \times 10^{10}$ cm. per sec (Sec. IV:6).

Wave-length $= 6500$ Å $= 6500 \times 10^{-8}$ cm.

Velocity = Frequency × Wave-length (Sec. II:5)

$$\therefore \text{Frequency} = \text{Velocity} \div \text{Wave-length}$$
$$= \frac{3 \times 10^{10}}{6500 \times 10^{-8}}$$
$$= .46 \times 10^{15}$$

$\therefore$ The vibration frequency of red light is $.46 \times 10^{15}$ vibrations per second.

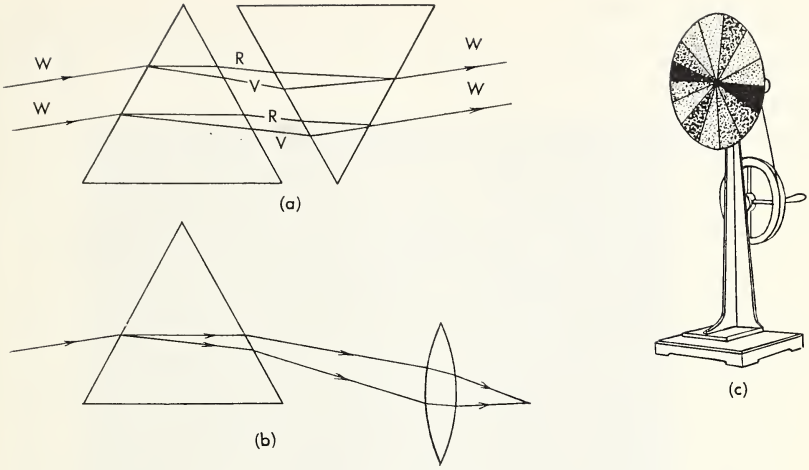


Fig. 19:2 Recomposition of the Spectrum into White Light. (a) By Reversed Prisms. (b) By a Converging Lens. (c) By Newton's Disc.

(b) Recomposition

Newton further supported his theory concerning the composite nature of white light by showing that the colours of the spectrum could be recombined, giving white light (Chap. 21, Exp. 16). He first arranged two prisms with their refracting edges in opposite directions. On passing white light through these reversed prisms, white light was obtained through them. Fig. 19:2a shows that the first prism disperses the colours, while the second prism recombines them by reversing the original refraction and causing the light waves to be superimposed on each other. A similar effect can be secured by using a converging lens to catch the dispersed coloured light from a prism. If this light is brought to a focus on a screen a spot of white light will be obtained (Fig. 19:2b). If the screen is moved beyond the focus, a reversal of the original colours will be obtained.

Newton also prepared a colour disc on which were coloured sectors whose sizes and colours corresponded fairly closely to the coloured bands obtained in a pure spectrum of white light (Fig. 19:2c). If this disc is strongly illuminated and rapidly rotated it will appear white. This phenomenon is due to what is called "the persistence of vision". Any visual impression on the retina of the eye persists for a short period of time after the cause has been removed. It is on this principle that movies are made to appear continuous. In reality, each picture is thrown on the screen for a fraction of a second, its image persisting in our vision until the next appears. Similarly, if the coloured disc is rotated rapidly enough, the impression produced by one colour persists, while impressions produced by all the other colours are received on the same portion of the retina. Thus all the colours of the spectrum will be superimposed on the retina, and will give the sensation of white light.

IV : 37 THE RAINBOW

The rainbow is a spectrum of sunlight formed by water droplets. A ray of sunlight entering a drop of water is refracted at A (Fig. 19:3a), the violet rays being refracted more than the red rays.

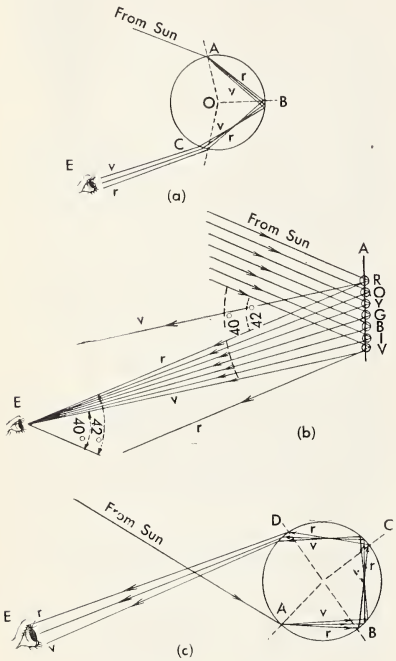


Fig. 19:3 The Rainbow

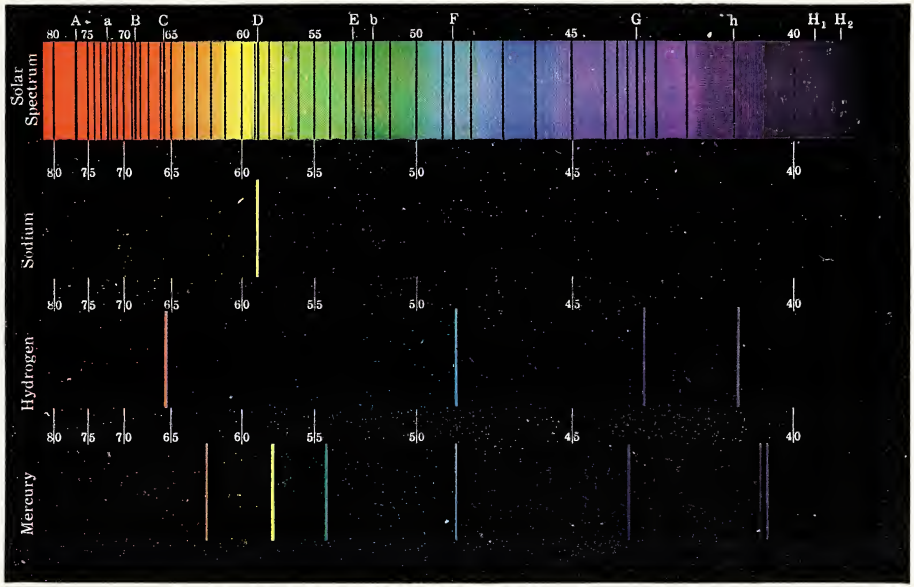
(a) Refraction and Total Reflection in a Raindrop.
(b) The Primary Bow.
(c) Double Reflection to Produce the Secondary Bow.

The refracted light is totally reflected at B and is again refracted at C so that the different colours are dispersed. Each drop of water forms its own little spectrum. In the actual bow which the observer sees, the red rays come at an angle of 42° from drops of water higher in the sky, and the violet rays come at an angle of 40° from drops of water lower in the sky (Fig. 19:3b). The other colours come from drops between these angles. The rainbow has the shape of a bow, since the eye of the observer is at the apex of a cone from which he sees the coloured rays refracted from drops, all of which must subtend approximately the same angle at the eye (between 40° and 42°).

Sometimes a larger, but fainter secondary bow is seen above the primary. The colours in it are reversed, the violet being on the outside. The light enters the lower part of the water drops, is refracted, and twice totally reflected before it leaves the drop (Fig. 19:3c). The light is refracted from the drops of water at angles of from 51° to 54°. The double reflection not only reverses the colours, but also absorbs more light thus causing the secondary bow to be fainter than the primary bow.

IV : 38 BEYOND THE VISIBLE SPECTRUM

So far in our study of the spectrum we have considered only those radiations to which the eye is sensitive. Actually the spectrum of sunlight extends well beyond its visible limits. Sir William Herschel, in 1800, on placing the blackened bulb of a thermometer in the various parts of the spectrum, discovered that the heating effect observed at the red end was continued when the thermometer was placed well beyond the visible limit. He thus indicated the existence of a wide range of invisible radiation beyond the red end of the spectrum (Sec. III:15). These **infra-red** radiations, as they are called, convey almost half of the sun's total outpouring of energy into space. They can penetrate mist, smoke and haze and hence are very suitable for distance photography, reconnaissance, photography in the dark, and detection of



Adapted from Erdmann's "Lehrbuch der Anorganischen Chemie."

Fig. 19:6 Spectrum Chart Showing Absorption Spectrum or Dark-Line Spectrum of the Sun, and Bright-Line Spectra of Sodium, Hydrogen and Mercury. *Note: A Continuous Spectrum is identical to the Solar Spectrum without the dark lines.*

Electromagnetic Wave Spectrum

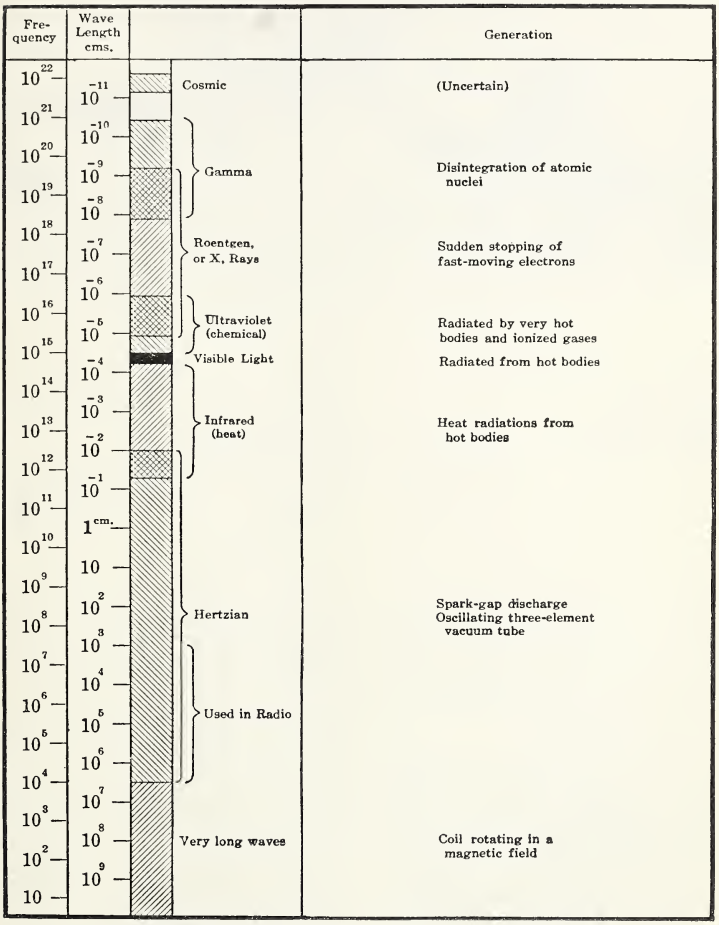
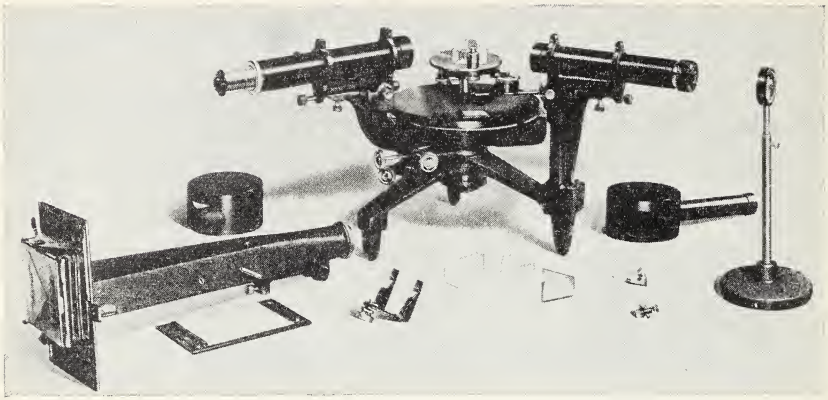
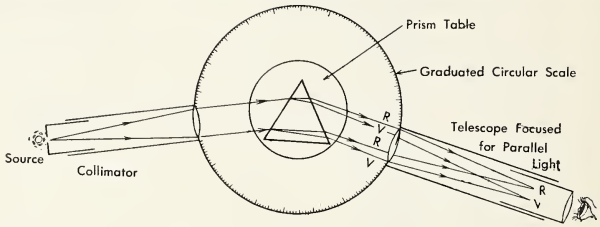


Fig. 19:4



(a) American Optical Company (Canada) Ltd.



(b)

Fig. 19:5

(a) Spectroscope.
(b) Optical System of Spectroscope.

forgeries or substitutions. Under these conditions special photographic film sensitive to infra-red must be used. These rays also have therapeutic value such as in the treatment of rheumatism and other aches and pains.

The year following Herschel's discovery of the infra-red, Ritter discovered, by its action in blackening certain silver salts, a band of invisible radiation beyond the violet, called the **ultra-violet.** Ultra-violet rays do have special photographic effects, and also make some substances such as vaseline and certain minerals "fluoresce" or give out "cold light". They have a highly beneficial effect on health, accelerating the manufacture of vitamin D under the skin. These ultra-violet rays are easily absorbed by mist, smoke and ordinary glass. Consequently, one readily recognizes the value of a holiday away from the city. For ultra-violet treatment one must be exposed directly to the sun's rays, or use windows of special "vita glass" which is transparent to some ultra-violet rays. Proper precautions must be taken as overtreatment can produce severe sunburn, as well as damage to the retina of the eye. Ultra-violet lamps simply consist of carbon or mercury electrodes between which an electric current produces an arc. Such lamps are usually fitted with quartz lenses which are transparent to the ultra-violet rays.

The presence of ultra-violet rays beyond the visible spectrum of white light may be shown by using a quartz prism in place of the glass prism in Fig. 19:1. If a sample of anthracene is placed beyond the violet it will be seen to fluoresce.

In addition to the invisible radiations

discussed above in connection with the solar spectrum, there exist other invisible radiations such as radio waves, X-rays, and gamma rays (rays emitted by radioactive substances). All these different radiations are propagated as waves with the same velocity as light, the difference in their properties being due to their different wave-lengths. The relationship between these various electromagnetic waves, as they are called, is shown diagrammatically in Fig. 19:4.

IV : 39 SPECTRUM ANALYSIS

The spectroscope is an important instrument by means of which the spectra of luminous bodies can be produced and measured. It consists of a tube called the collimator (Fig. 19:5), at one end of which is a convex lens and at the other end an adjustable vertical slit. The length of the tube is equal to the focal length of the collimator lens, so that when the slit is illuminated by light from the source, *S*, under examination, a parallel beam can be directed onto a prism situated on a small turn-table at the centre of the instrument. The dispersed beams produced by the prism are received by a telescope focused for parallel light and fitted with cross-wires. This telescope can be moved round a circular scale against which the deviations of the constituent parts of the spectrum formed can be measured. The examination in this way of the light from different luminous bodies reveals that each spectrum is characteristic of the source, and a study of these spectra yields much valuable information to the physicist and astronomer. Accordingly we shall briefly consider here some of the more important spectra and their significance (Fig. 19:6).

Continuous Spectra: These consist of a number of coloured bands each shading off gradually into the next. They are produced by incandescent solids, e.g., arc-lamps, white-hot iron, etc.

Line Spectra: Incandescent gases and vapours emit light which when analysed produces spectra consisting of a number of well-defined coloured lines or coloured images of the slit. Each element has its own characteristic line spectrum which provides a certain and accurate means of identifying the element (Exp. 17, Chap. 21). The presence of even a minute quantity of an element in a mixture can be detected by spectroscopic analysis, and it is interesting to note that the method has been the means of discovering new elements. If the spectrum of a substance contains lines which do not correspond with those of any known element, the obvious conclusion is that there is present an element as yet not known. In this way the elements caesium and rubidium were discovered by Bunsen.

Line spectra can be produced by the Bunsen flame only in the case of substances which are easily vaporized. Other substances must be vaporized, using an electric arc or a spark discharge. The spectra of incandescent gases are usually obtained by means of special tubes containing a sample of the gas at low pressure through which the discharge from an induction coil is passed (Fig. 19:7).

Fig. 19:7 An Electrical Discharge Tube.

Absorption Spectra: If a sodium flame is set up between the slit of a spectroscope and a high-power electric lamp (Fig. 19:8), a dark line will be observed in the continuous spectrum of the light from the relatively hotter lamp in a position corresponding to that of the

yellow line of the incandescent sodium vapour. With other vapours dark lines would be formed in positions corresponding to their line spectra. A spectrum

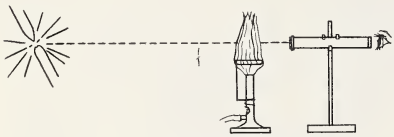


Fig. 19:8 The Production of an Absorption Spectrum.

crossed by dark lines in this way is called an absorption spectrum, and it was found that all substances when interposed in the path of light originating from a higher temperature source absorb from it light of the same wave-length that they themselves emit.

The Solar Spectrum is an absorption spectrum containing hundreds of dark lines carefully studied by Fraunhofer in 1814. These lines are due to selective absorption from the radiation emanating from the extremely hot core of the sun by the relatively cooler gases in the sun's atmosphere. Most of the lines have been found to correspond to lines in the spectra of elements present on the earth, and we have thus good grounds for believing that the chemical components of the sun and the earth are similar. A certain group of lines did not correspond with those of any known element. They were accordingly attributed to an element which was named helium, and which was ultimately discovered on the earth twenty-six years later. The constitution of the stars is determined in a similar way from an examination of their absorption lines.

IV : 40 NATURE OF COLOUR

(a) Colour

We have already established that colour is a property of light waves (Sec. IV:36). It may be defined generally, as the response of vision to different wave-lengths of light. Colour is the alphabet in our visual language, through which we make interesting our description of things and ideas which otherwise would be dull and prosaic. Our present knowledge and use of colour is based largely on the sciences of psychology, chemistry, and physics.

Psychology considers colour through the physical operation of the eye and the mental impression created by colour on the brain. As a result, the actual perception of colour is a highly personal experience which may be influenced by such factors as health, fatigue and response of the eye to colour (colour-blindness). According to psychologists the average person recognizes four distinct primary colours, red, yellow, blue and green. Colours do have a strong influence on people. Tensions can be heightened or relaxed through a change in colour harmonies; a feeling of warmth or coldness can be obtained by colour schemes used; colour can be stimulating or restful, it can attract or it can repel.

Chemistry deals with the production of materials which have the ability to absorb or reflect part of the light which falls upon them. These are chiefly dyes and pigments. The explanation for the colours of these materials is given in part (b) below.

Physics deals with colour from the standpoint of differences in wave-lengths of the coloured lights, and the effects of superimposing these on one another. The additive theory of colour to explain these effects is discussed in part (c) below.

These three colour theories are the basis for our modern usage of colour. Though separate, they are also interdependent. The range and intensity of the colours we see depend upon the quality and quantity of light, the nature of the

surface visible, and our ability to see and interpret what meets our eyes.

(b) Colour of Objects—The Subtractive Theory

There are three colours, yellow, red, and blue, which in pigments are the source of all other colours. By mixing these three colours in the right proportion, all other colours may be obtained. No mixture of other colours will produce any of these three colours. For this reason yellow, red, and blue are called **primary colours.** A colour chart has been prepared (Fig. 19:9) in which these primary colours are placed the

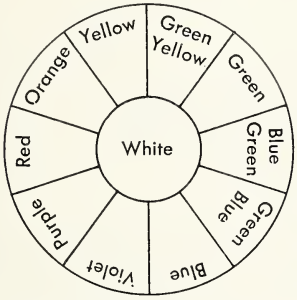


Fig. 19:9 A Colour Chart.

same distance apart along the edge of the circle. Mixing any two primary colours produces a third colour called a **binary colour** which is intermediate between those primaries, e.g., yellow and red produce orange. Various **hues** can be produced by mixing a binary colour with a primary colour used in making the binary, e.g., yellow and orange produce yellow orange. Certain colours seem to strengthen each other when they are seen together, and hence are said to be **complementary** to each other. In the chart the colours on the opposite sides of the circle are complementary.

White is the total addition of colour, and not, as often believed, the absence of colour. It is produced when a surface reflects all colours equally. Black, on the other hand, is perceived when a surface absorbs all colours and reflects none. Colour, then, is the result of partial absorption, and consequent subtraction, of a band of colour from the spectrum. The surface of an object will appear red when it is of such nature that it absorbs all but the red wave-lengths of the spectrum, and reflects these red wave-lengths (Chap. 21, Exp. 18). When we mix pigments, each one subtracts certain colours from white light, and the resulting colour depends upon the light that is not absorbed. For example, if we mix a blue pigment with a yellow one we get a green colour. The blue subtracts or absorbs all colours from white light, except green, blue and violet, while the yellow subtracts all except green, yellow and orange. Green is the only colour not subtracted by either pigment. For this reason the two pigments produce green.

Similarly, transparent objects are able to absorb or subtract certain colours from white light. If white light is passed through a piece of red glass, the glass absorbs all light except red, and a little orange, and we obtain red light (Fig. 19:10a). Objects that are transparent to only one colour are called colour **filters.** The combination of a yellow and a blue filter placed over a single white light source will result in a green light because all except the green wave-lengths of the spectrum have been absorbed (Fig. 19:10b). Similarly a combination of three filters, each corresponding to a primary colour, will absorb all the colours and allow practically no light to pass (Fig. 19:10c). (Chap. 21, Exp. 18).

The light which falls upon an object can also determine its colour. If the light does not contain all the colours of

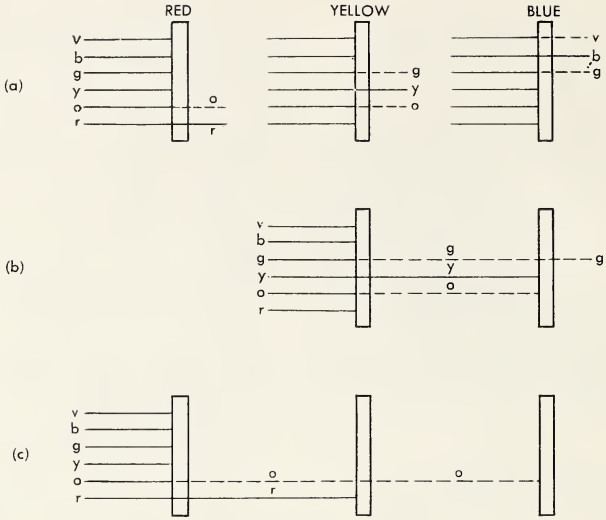


Fig. 19:10 Colour Filters (The Subtractive Theory)
(a) Transmission of Light by Different Coloured Filters.
(b) Combination of Yellow and Blue.
(c) Combination of Red, Yellow, and Blue.

the spectrum then the true colour of the object will not be observed. The light given off by a light bulb does not contain all the colours found in sunlight. For this reason an article of clothing may appear quite different in the sunlight than when seen under artificial light.

(c) Coloured Lights—The Additive Theory

Having produced different coloured lights by the use of filters, two or more of these may be added together to produce still other colours. The three colours, red, green and blue, which combine to produce white are called the three **primary colours** for lights. None of these primary colours can be produced by adding other colours of lights. However, any other colour can be produced by a proper combination of them (Fig. 19:11). For example, red and blue light when combined produce violet; red and green light added together

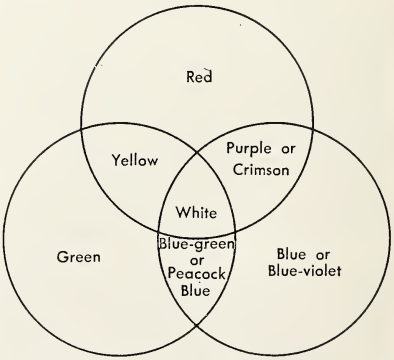


Fig. 19:11 Coloured Lights (The Additive Theory).

will produce yellow, and so on. The colour resulting from the simple combination of each pair of primary colours is complementary to the third primary; for example, violet is complementary to green, and yellow is complementary to blue. If we superimpose these complementary coloured lights we again get white light.

Contrast how colour is obtained in mixing pigments with how it is obtained in mixing coloured lights. In the former the resulting colour is the one not absorbed or subtracted by either pigment (the subtractive effect); in the latter the resulting colour is obtained by adding the effect of the individual colours (the additive effect). Both methods are widely used in industry. The mixing of pigments to produce our multi-coloured paints, the many vegetable and synthetic dyes for treating fabrics, textiles, etc., and the use of filters in photography, all are applications of the subtractive effect mentioned above. The additive effect is applied in the use of coloured spotlights to illuminate actors on stage, or participants in a carnival or pageant, as well as to produce changing and spectacular effects in the illumination of Niagara Falls and in some of the coloured advertising that is so common nowadays.

Colour is of tremendous importance in industry. Its use in advertising has been mentioned above. Bright contrasting colours of paint on walls, floors, and machinery not only provide better visual conditions but also boost morale, speed up production, and affect safety records. Colour codes are used in business for invoicing, in electrical industries to denote polarity, voltage, resistance, and the like, and in shipping to encourage due precautions in the handling of dangerous articles. All, of course, are familiar with its use in traffic control.

(d) Colour Vision

The way in which light is changed into the sensation of sight is not definitely known. The most widely accepted theory, the Young-Helmholtz theory, states there are three sets of colour nerves in the normal eye. One of these sets of nerves responds only to blue light, another set to green light, and the third set to red light. The colour of an object is determined by the relative degree of stimulation of each type of nerve.

A small proportion of men (about 3½%) and women (about ½%), do not have all three of these sets of colour nerves and hence they do not receive the same sensation of colour from an object as a person with all three sets of colour nerves. Such people are said to be colour blind. By this we do not mean that they do not see colour in objects, but that they do not see the same colours as a person with normal eyes. This defect is inherited through the mother; it usually exists from birth; and there is no known cure for it.

Because a colour-blind person sees a different colour pattern in a landscape from the pattern seen by a person having normal vision, colour-blind observers are very efficient in detecting camouflage and are so used during wars. Some colour-blind persons are unable to distinguish reds and greens from each other and, consequently, have real difficulty with traffic signals.

IV : 41 COLOUR PRINTING

Most of the coloured pictures in books and magazines are made by using four separate printing-plates, each plate printing a different coloured ink on white paper—yellow, red, blue and black, in that order. The plates are made from four photographic negatives of the same subject. These negatives are made through fine-meshed coloured filters,

each stained with one of the three primary colours (the black one is not actually used in the creation of the coloured picture in Fig. 19:12). The fine-meshed filter breaks the subject into numerous small dots on the negative. The filter determines what colours can pass through the camera and become recorded on the negative. Thus dots representing only certain colours are recorded on each negative. The first plate reproduces the dots of the first negative in yellow ink on white paper. The second plate reproduces those of the second negative in red ink on or between the yellow dots, etc. The final effect is one of individual and overlapping dots of colour. Where a dot of one colour overlaps a dot of another colour a new colour may be obtained. The eye blends these dots of the four original and the mixed colours to give the total effect.

IV : 42 CHROMATIC ABERRATION

Since the action of a convex lens is similar to that of two prisms with their bases in contact (Sec. IV:28), incident rays, in addition to being deviated to form a convergent beam will be dispersed on passing through the lens. The various colours are brought to different foci on the principal axis, the focus for violet rays being nearer the lens than that for red rays (Fig. 19:13a). In consequence it is impossible to obtain a well-defined image when white light is used, the image received on a screen having a red fringe when placed at *A* and a blue fringe when placed at *B*, there being no position between *A* and *B* at which the image is sharply in focus. This non-focusing of light of different colours is known as **chromatic aberration.** By using two reversed prisms, one of crown glass and the other of flint glass which has a higher index of refraction, it is possible to obtain a non-dispersive combination which still has the power of deviating the light (Fig. 19:13b). Similarly it is possible to combine a convex lens of crown glass with a weaker concave lens of flint glass so that the dispersion produced by the two lenses is equal and opposite. A lens combination of this type is called an achromatic (without colour) lens. These achromatic combinations are still converging and accordingly can be used as objective lenses in telescopes, field glasses, cameras, and other optical instruments.

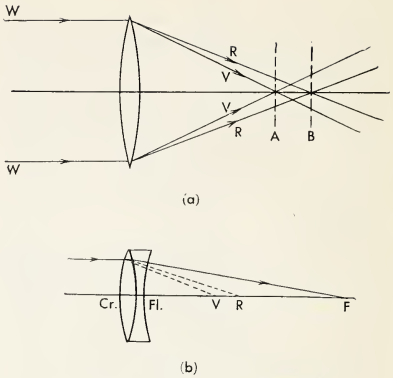
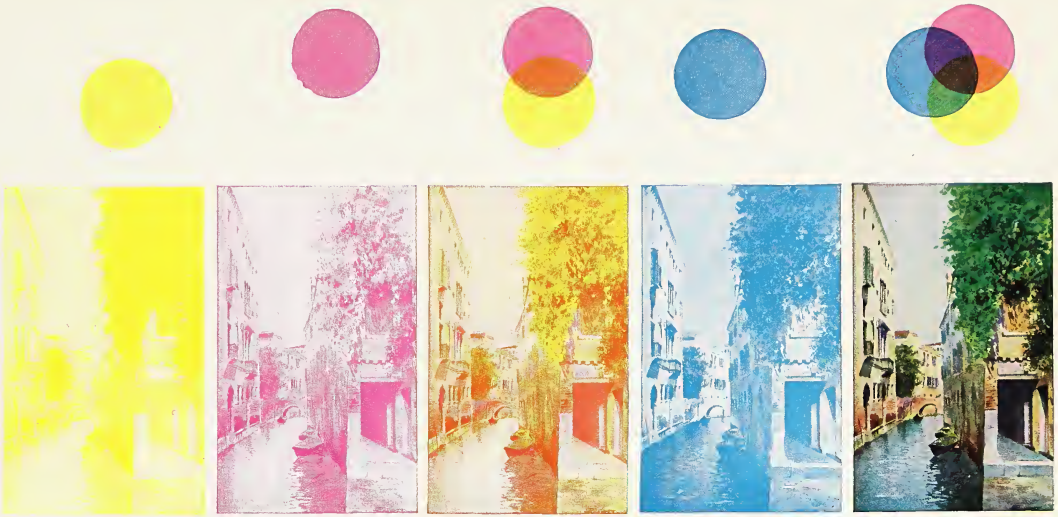


Fig. 19:13 Chromatic Aberration.
(a) Its Cause.
(b) Its Correction—An Achromatic Lens.



1 2 3 4 5

Fig. 19:12 Three-Colour Process of Printing.

1. Yellow Plate, negative made through a violet-green filter; 2. Red Plate, negative made through a green-yellow filter; 3. Red on yellow; 4. Blue Plate, negative made through a red-yellow filter; 5. Yellow, Red, and Blue combined. Notice the various colours and shades in the finished print. *Note: In Four-Colour Printing a Black Plate is Used in Addition to the Yellow, Red and Blue Plates.*

IV : 43

QUESTIONS

1. (a) Define: spectrum, dispersion.
(b) Why does a prism deviate violet light more than red light?
(c) Calculate the vibration frequency of violet light (See table, p. 214, for wave-length of violet light).

2. Describe and explain three methods for recombining the spectral colours into white light.

3. Explain how refraction produces a solar spectrum (rainbow).

4. Write a note on (a) infra-red rays, (b) ultra-violet rays, indicating,
(i) how each differs from visible light.
(ii) how each can be detected.
(iii) how each is used.

5. (a) What is the purpose of a spectroscope?
(b) Distinguish a line spectrum from (i) a continuous spectrum, (ii) an absorption spectrum. How is each produced?

6. What is the physicist's explanation of (a) coloured light, (b) white light?

7. (a) In the subtractive theory of light what are (i) the primary colours, (ii) complementary colours?
(b) Why does a rose appear red, grass green and a dandelion yellow when seen in sunlight? State a general rule for the colour of an opaque object.
(c) Why does red glass appear red, blue glass appear blue, and ordinary glass appear colourless, in white light? State a general rule for the colour of transparent objects.
(d) What would be the colour of the objects in (b) when viewed through (i) a red-glass filter, (ii) a blue-glass filter?
(e) Why is it unwise to buy coloured clothing by artificial light?

8. (a) How does the additive theory of light differ from the subtractive theory?
(b) In the additive theory what are (i) the primary colours, (ii) complementary colours?
(c) If coloured spotlights are shone on a white screen,
(i) what colour will be obtained if red and blue lights are used?
(ii) what coloured lights should be used to produce yellow?

9. How does the physicist account for the difference between mixing coloured lights and coloured pigments?

10. What is colour-blindness? How does the Helmholtz theory explain it?

11. Describe the process of colour printing.

12. (a) What is chromatic aberration?
(b) What is an achromatic lens?

CHAPTER 20 OPTICAL INSTRUMENTS

IV : 44 THE CAMERA

The photographic camera is essentially an enclosed box or bellows chamber with an opening or aperture in the front through which light from an object passes. The image is recorded on a light-sensitive material at the back.

(a) History

The evolution of the camera is credited to men like Roger Bacon, 1267, and Leonardo da Vinci, 1519, who described and developed the pin-hole camera. Baptista Porta, 1553, and Johann Kepler, 1604, later added a lens and then a combination of lenses. From these simple beginnings have come many types of cameras ranging from the relatively inexpensive family-type cameras, through the more expensive press and movie cameras, up into the highly specialized cameras used in television and in aerial photography.

(b) Structure

All cameras are constructed on the same basic principles as were the first crude, wooden, box-cameras. The essential parts of a camera (Fig. 20:1) are:

1. A light-tight box or bellows.
2. A lens to form the image on the film.
3. A shutter (and diaphragm) to con-

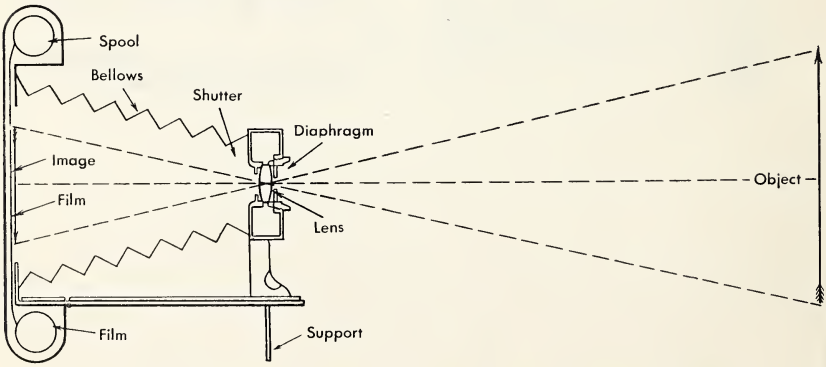


Fig. 20:1 The Essential Parts of a Camera and How it Forms an Image.

trol the amount of light that is admitted to the film.

4. A negative holder or carrier to hold films in position during exposure.
5. A view-finder or ground glass to determine picture area.

By the addition of special accessories and other refinements, the utility and scope of the camera may be extended to meet almost any photographic requirement.

(c) Focusing

In order to focus objects at different distances from the camera, the lens is often attached to a bellows so that it may be moved nearer to the light-sensitive plate or film, or farther away. In section IV:30 we learned that as the object is moved nearer to a converging lens, the real inverted image gradually moves farther away from the lens. This should indicate how to focus the camera. For distant objects the lens is moved so that the sensitive plate is located at its principal focus. For close objects, the lens is moved away from the sensitive film, for now the image is focused beyond the principal focus of the lens. Most cameras include a focusing scale on the lens mount or on the bed of the camera and many have built-in range finders to assist in focusing.

(d) Light Control

As has been indicated previously the film or plate in a camera contains materials which are sensitive to light. The plate is coated with an emulsion consisting of gelatine and a silver salt. Light decomposes this silver salt so that when "developed" and "fixed" a negative is obtained consisting of a dark deposit of silver in places corresponding to the light parts of the original image, and light transparent portions in positions corresponding to the darker parts of the original image.

One sees, therefore, that it is necessary to be able to control the amount of light that enters the camera. This is done in two ways: (1) by controlling the size of the aperture or opening through which the light enters; and (2) by regulating the length of time that the light is permitted to enter. The former is accomplished by using a variable diaphragm behind the lens which enables the aperture to be varied, and the latter by means of a shutter, which is a delicate mechanical device, often consisting of a number of overlapping thin metal blades, held in position by means of springs. On being released or tripped, when taking a picture, the shutter opens and closes for a measured time interval.

When using a small aperture a longer exposure is required than with a large one. It is wise practice to use as small an aperture as possible as this permits using the central part of the lens only, and prevents errors due to inaccuracies near the edges of the lens. Also greater depth of focus is obtained, that is, objects at relatively smaller and greater distances from the camera will still be sufficiently in focus to look clear in the print.

IV : 45 THE HUMAN EYE

The eye is the sense organ enabling light to be perceived. This, the most wonderful of all optical instruments, can be compared in many respects to a camera (Fig. 20:2).

(a) Structure and Action

The eyeball is approximately spherical in shape and slightly less than one inch in diameter (Fig. 20:3). The wall of this sphere is composed of two major layers: (1) the outer covering, the sclerotic coat, is a tough opaque white substance forming the white of the eye. The front portion of this sclerotic coat forms a transparent, curved section called the

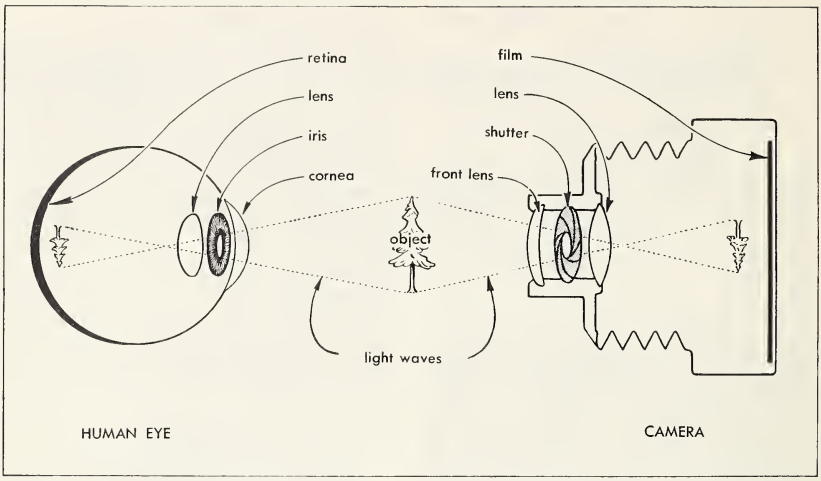


Fig. 20:2 Comparison of the Eye and the Camera.

cornea that protects the eye and aids in refracting light. (2) The inner layer, the **choroid coat**, is black to prevent internal reflection and to protect the light-sensitive parts of the eye. It is also largely nutritive in function. The aqueous and vitreous **humours** are jelly-like materials filling the spaces within the eyeball, which help to keep its spherical shape.

Behind the cornea is a coloured diaphragm called the **iris**. This is really an extension of the choroid coat, and its colour is mainly due to the variable amounts of pigment in it. In the centre of the iris is a circular aperture, called the **pupil**, which appears black due to the black interior of the eye. The iris contains muscles, which dilate and contract the pupil adjusting the eye to different amounts of light. The pupil is dilated in dim light, and contracted in bright light. This action occurs involuntarily, i.e., without any control on our part, and hence is called the **iris reflex**. To note its action, stand in front of a mirror in a dark room for several minutes. Then turn on the light and note the immediate contraction of the pupil. Optometrists use drugs, such as atropine, to temporarily dilate the pupil and permit internal examination of the eye.

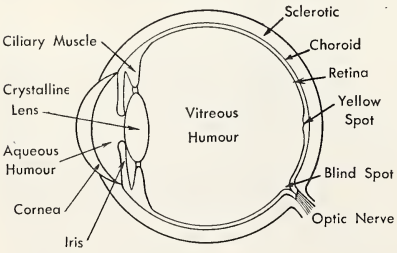


Fig. 20:3 The Structure of the Eye.

Behind the pupil and iris is the **crystalline lens**. This is a transparent structure, made up of numerous concentric layers, increasing in density toward the middle.

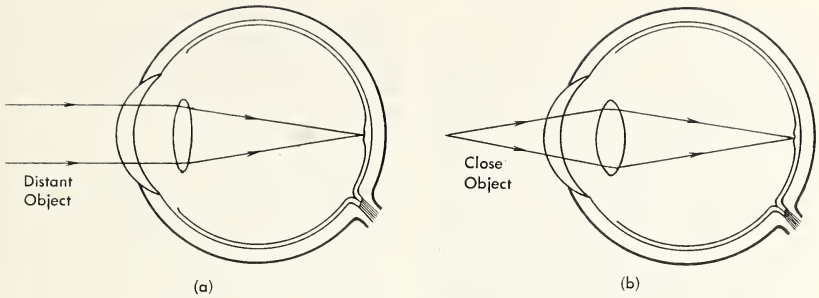


Fig. 20:4 Lens Accommodation. (a) Distant Vision (b) Close Vision.

The curvature of its front surface is considerably less than that of the back surface. Both of these features tend to diminish distortion of the image. The lens is encased in an elastic capsule and is held in place by suspensory ligaments which are attached to the choroid coat. These ligaments hold the lens under a certain tension so that it normally tends to be flattened and adjusted for distant vision. In the choroid layer near the suspensory ligaments are small **ciliary muscles**. The contraction of these muscles tends to relieve the tension exerted by the suspensory ligaments on the lens which therefore becomes more convex and so adjusted for close vision. The adjustment of the lens to form a sharp image on the retina is called **accommodation** (Fig. 20:4). The normal eye can accommodate itself to objects ranging from infinity to a point about twenty-five centimeters or ten inches from the eye. This latter point is known as the nearest point of distinct vision. Objects closer to the eye than this cannot be clearly focused by the unaided eye.

The **retina** is the innermost layer of the eye and is sensitive to light. The retina is composed of visual cells, nerve cells, and the fibres which connect these and conduct the nerve impulses to the brain. The visual cells are of two types, called rods and cones, so named because of their characteristic rod and cone shapes. The rods are concerned with colourless and dim-light vision, while the cones handle colour and bright-light vision. The nerve cells integrate and relay the impulses which they receive, to the optic nerve, and through it to the brain. That part of the retina where the optic nerve enters the eye, is insensitive to light and is known as the blind spot. Its existence can be readily demonstrated as shown in Fig. 20:5. The most sensitive part of the retina is a small yellow spot located on the principal axis of the lens. An object being viewed is automatically focused on this area.

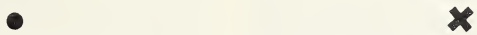


Fig. 20:5 The Blind Spot. Close one eye. Hold the book at arm's length. Stare at the X. Move the book toward you. At a certain distance the circle will disappear, for its image is formed on the blind spot.

(b) Defects of Vision and Their Correction

In view of the delicate adjustments made by our eyes and the way we abuse them these days with excessive reading, watching movies, television, etc., it is only natural that many abnormalities or defects develop. Here, however, we are only concerned with defects or errors caused by refraction of light.

When an eye with no refractive error is at rest, parallel rays of light are focused exactly on the retina. Many eyes, owing to abnormalities of the refracting mechanism, do not focus the light exactly on the retina. Such defects of the eye can in large measure be overcome with the aid of suitable lenses (spectacles).

1. Near-sightedness

Persons suffering from this defect are unable to focus on distant objects distinctly, although objects close to the eyes are clearly seen. This is due to the axis of the eyeball being too long or the crystalline lens being too powerful, so that rays from a distant object tend to be focused in front of the retina (Fig. 20:6a). This defect is largely hereditary, but is also aggravated by too strenuous use of the eyes during the early years. Concave lenses placed in front of the eye will make the light more divergent and bring the image to a focus on the retina.

2. Far-sightedness

A far-sighted person cannot see clearly objects close to the eye although distant objects may be distinctly seen. The defect is due to the axis of the eyeball being too short or the crystalline lens not sufficiently converging so that rays from a nearby object tend to converge to a point behind the retina (Fig. 20:6b). It is the most common of refractive errors of the eyes and is present to some degree in about two-thirds of all adults. Convex lenses placed in front of the eye will reduce the divergence of the rays which can then be focused on the retina.

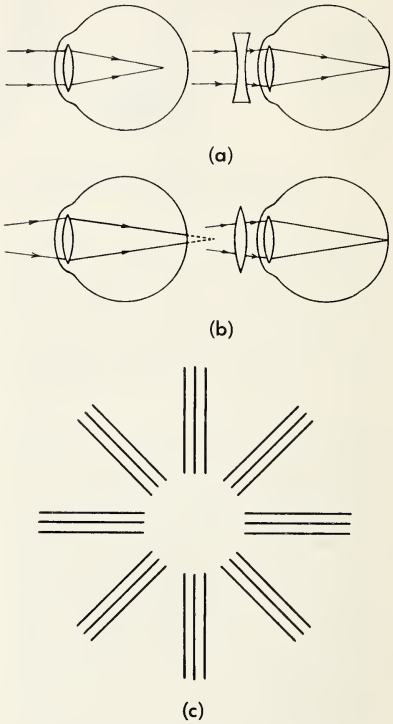


Fig. 20:6 Defects of Vision.

(a) Near-sightedness, Corrected by Concave Lens.

(b) Far-sightedness, Corrected by Convex Lens.

(c) Test for Astigmatism. Do all the lines appear equally distinct to you?

3. Astigmatism

As a result of this defect lines in different planes are brought to different foci and in consequence one set of lines

will be in sharp focus, while others inclined to them are blurred and indistinct (Fig. 20:6c). For example, an astigmatic eye may clearly discern all the vertical lines of a building, while those in a horizontal plane are scarcely perceived. The main cause of this defect is the lack of sphericity of the cornea, in which the vertical section is frequently more curved than the horizontal. To overcome the defect cylindrical lenses are used to assist refraction in the plane of least curvature of the cornea. Astigmatism is present to varying degrees in most eyes.

4. Presbyopia

This is a defect of age resulting from the loss of accommodation brought about by hardening of the crystalline lens, or of the ciliary muscles. It is evidenced by both near and far objects being indistinct. Clear vision by the unaided eye is possible over only a very restricted range. Two pairs of spectacles are required by such people, one pair (convex) for reading, and another pair (concave) for distant vision. Both purposes may be served by a pair of bifocal lenses, the top part being used for distance, and the lower part for reading.

IV : 46 THE MAGNIFYING GLASS

The apparent size of an object depends on the angle it subtends at the eye. This angle is known as the **visual angle** of the object, and in order to see a small object clearly one instinctively brings it close to the eye, with consequent increase in its visual angle. With the unaided eye there is, however, a limit to which this process can be carried. This is reached when the object is at the nearest point of distinct vision (normally 25 cm. or 10 in.) at which position the object is seen most clearly. If brought within this natural limit the eye cannot accommodate itself to the widely diverging rays from the object without undue strain. With the use of a short-focus convex lens, however, it is possible to bring the object even closer, thereby enabling it to be seen still more distinctly without straining the eye. The object is placed inside the focus of the lens at such a position that the eye focuses the magnified virtual image formed at the nearest point of distinct vision. The path of the rays by which the eye sees the image is shown in Fig. 20:7.

The magnifying power of such a lens is the size of image on retina when object is viewed through the lens divided

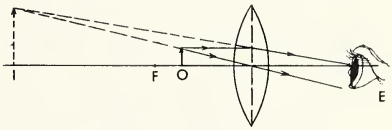


Fig. 20:7 The Action of a Magnifying Glass. The image is focused at the least distance of distinct vision.

by size of image on retina when object is viewed directly at the least distance of distinct vision

$$= \frac{\text{least distance of distinct vision}}{\text{focal length of the lens}}$$

$$= \frac{10 \text{ in.}}{f} \text{ or } \frac{25 \text{ cm.}}{f}$$

In using a magnifying glass we focus the image at the least distance of distinct vision by moving the lens back and forth from the object. A near-sighted person might focus on an image 7 inches from the eye, for example, whereas a far-sighted person would change the lens-object distance so that the image might be 13 inches from the eye. If $f = 1$ inch., the former person would only get a magnification of $7 \times$, whereas the far-sighted person would get a magnification of $13 \times$. To save argument the average value for least distance of distinct vision has been set at 10 inches.

Note:

$\because$ Magnification $= \frac{H_i}{H_o} = \frac{D_i}{D_o}$ (Sec. IV:32)

and D_i = least distance of distinct vision
= 10 in. or 25 cm.

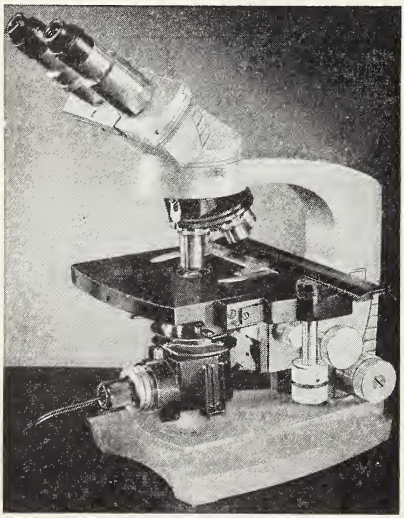
and D_o = focal length (f) approximately

$\therefore$ Magnification $= \frac{10 \text{ in.}}{f}$ or $\frac{25 \text{ cm.}}{f}$

IV : 47 THE COMPOUND MICROSCOPE

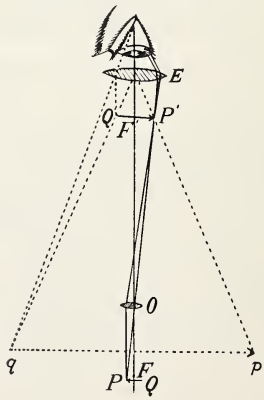
The compound microscope is very widely used to produce great magnifications of small objects. The instrument (Fig. 20:8a) consists mainly of a convex lens of short focal length, called the **objective**, O, and a second convex lens, called the **eyepiece**, E. These lenses are mounted in a tube of adjustable length. The object, PQ, to be viewed is placed just outside the principal focus, F, of the objective (Fig. 20:8b). This produces a real magnified image of the object at $P'Q'$, and this image falls inside the principal focus, F', of the eyepiece which acts as a simple magnifying glass. Through this lens the eye sees a large virtual image, pq, when the length of the tube is properly adjusted so that the image is sharply in focus at the nearest point of distinct vision. As with the magnifying glass, the position of the virtual image depends upon the accommodation of the observer's eye.

The magnification produced by the compound microscope is obtained in two stages. Both lenses individually produce a magnified image, so that the total magnification is the product of the two. Microscopes for visual use can be constructed to give magnifications of 2000 and above, the higher magnifications being obtained by using objective lenses of very short focal length. Often such lenses are designed to employ a medium of cedar oil between the specimen and the objective (Oil-Immersion Microscopes). This medium increases the light-gathering power and the resolving power of the objective by reducing reflection and scattering of light at the surface of the lens. Single lenses of very short focal length give images which are



American Optical Company (Canada) Ltd.
(a)

Fig. 20:8 The Compound Microscope.



(b)

Ray Paths in the Compound Microscope.

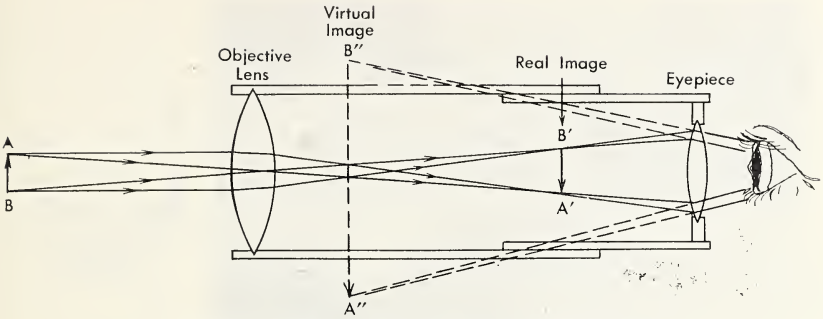


Fig. 20:9 The Refracting Astronomical Telescope.

greatly distorted, and which have coloured edges. To avoid this the objectives of actual microscopes are usually compound achromatic lenses (Sec. IV:42).

Microscopes generally have a concave mirror, and frequently a condensing lens above it, to focus sufficient light on the object being examined. The invention of the microscope in 1590 by Zacharias Janssen, with the many improvements added since then, has contributed immensely to the advances made in medicine and public health, as well as revealing many marvels of plant and animal life, and hidden secrets of the mineral kingdom.

IV : 48 THE TELESCOPE

(a) Refracting Telescope

The method by which the telescope works is similar to that of the microscope. The refracting telescope consists of an arrangement of two convex lenses for viewing very distant objects (Chap. 21, Exp. 19). The objective should have a very great focal length, for the greater the focal length the larger will be the image of an object at infinity. It should also be of large diameter to enable a maximum amount of light to be collected, thereby producing a brighter image. This lens will produce a real inverted image at its principal focus. This should be located just within the principal focus of the eyepiece through which the eye sees a magnified virtual image (Fig. 20:9).

The magnifying power of the telescope is approximately equal to the focal length, F, of the objective divided by the focal length, f, of the eyepiece.

$$\therefore \text{Magnifying power} = \frac{F}{f}$$

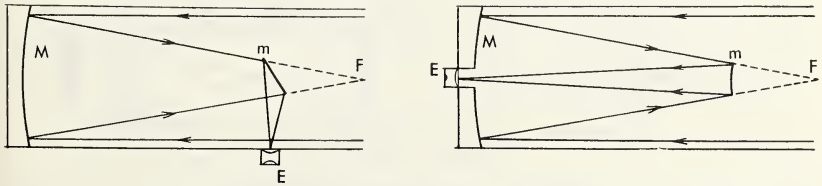


Fig. 20:10 Two Forms of the Reflecting Telescope.

Palomar Mountain Observatory, California.

Star Newspaper Service

(b) Reflecting Telescope

Reflecting telescopes are used for astronomical purposes. The objective is a parabolic mirror (Sec. IV:19) which collects light from the distant object. Since the light is reflected back toward the object, a means of viewing the image with an eyepiece necessitates the use of an additional mirror or prism (Fig. 20:10).

Large reflecting telescopes include the 74 inch diameter telescope at the David Dunlap Observatory at Richmond Hill, Ontario, and the 72 inch telescope at the Dominion Astro-Physical Observatory near Victoria, British Columbia. Larger telescopes of this type are located at Mount Wilson, California (100 in.) and at Palomar Mountain, California (200 in.). This latter is the largest telescope in the world, having one million times the light-gathering power of the human eye.

(c) Terrestrial Telescope

The drawback to the astronomical telescope is that the image is inverted. For observing familiar terrestrial objects a telescope requires an image-erecting system. The simplest means of obtaining this is to insert a third convex lens to re-invert the image (Fig. 20:11). Such terrestrial telescopes are used by surveyors, by mariners and by military men.

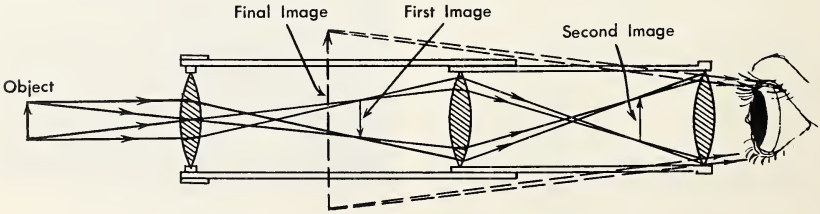


Fig. 20:11 The Terrestrial Telescope.

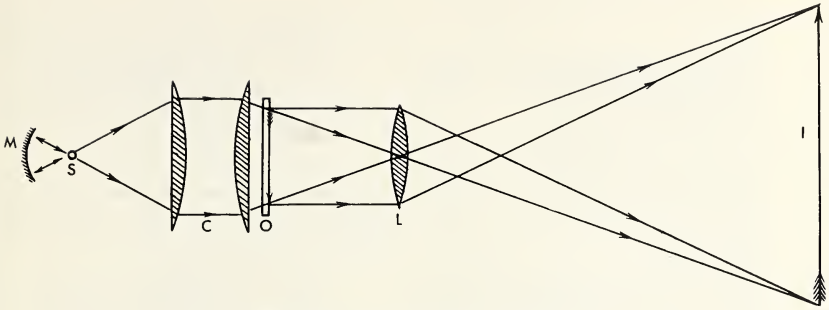


Fig. 20:12 The Slide Projector.

IV : 49 THE SLIDE PROJECTOR

The purpose of the slide projector is to cast a magnified image of a slide or coloured transparency upon a screen some distance away. Fig. 20:12 shows the essential structure of such a projector. A study of the paths of the light rays shown in the diagram will serve as an excellent review of some of the work covered earlier in concave mirrors and converging lenses.

For this instrument a very powerful light source is needed. This is placed at the centre of curvature of a concave reflector (mirror) *M*, so that many rays that tend to be lost, on hitting this mirror are reflected back on themselves thereby intensifying the light source. It is also placed at the principal focus of a condensing lens system, *C*. As a result the diverging cone of rays from the light source on striking this condenser is concentrated into a parallel beam of light and sent through the slide, *O*. The slide must be located outside the principal focus of the objective, *L*. This lens as a result produces a real, enlarged, and inverted image on the screen. The slide is always inserted upside down in the carrier, so that its image will be erect on the screen, *I*. The size of the image may be increased by increasing the distance between the projector and the screen. The objective is contained in a moveable mount, to permit focusing the image for different distances of projection. Optically the motion-picture projector and slide projector are similar.

IV : 50 QUESTIONS

1. Compare and contrast the lens camera and the human eye under the following headings:

(a) structure.
(b) focusing.
(c) light control.

2. What adjustments would you make in your camera for taking pictures under the following conditions:

(a) an object close to the camera.
(b) an object distant from the camera.
(c) an object on a cloudy day.
(d) an object on a sunny day.
(e) a moving object.

3. The focal length of a camera lens is 3.0 in.

(a) How far from the film is the lens when a man standing 12 ft. from the

camera is brought into focus upon the film?

(b) How tall will be the man's image on the unenlarged picture if his height is 6 ft.?

4. (a) What is meant by (i) iris reflex, (ii) lens accommodation?

(b) Why do your eyes become more sensitive when you go into a darkened room?

(c) By means of a diagram show how the lens of the eye changes when the object viewed is moved closer to the eye.

5. Describe, with the aid of diagrams, (a) near-sightedness, (b) far-sightedness, (c) astigmatism, under the following headings:

(i) cause.
(ii) effect.
(iii) correction.

6. (a) What is the purpose of the magnifying glass?

(b) Describe the image you see through a magnifying glass.

(c) Calculate the magnifying power of such a glass having a focal length of (i) 3.0 cm. (ii) 1.5 in.

(d) What would be the size of the image of a crystal 3 mm. long when viewed through each of the magnifying glasses in 6 (c)?

7. (a) Make a sketch of a compound microscope locating the two images.

(b) If the first (objective) lens magnifies the object 8 times and the eyepiece magnifies the real image 20 times, how many times is the final image larger than the object?

8. Discuss (a) the refracting telescope, (b) the reflecting telescope and (c) the terrestrial telescope, as to:

(i) essential parts.
(ii) how each works.
(iii) types of images obtained.

9. In a slide projector:

(a) Where is the light source relative to (i) the concave reflector, (ii) the condensing lens? Why is it placed in this position?

(b) Where is the slide relative to the principal focus of the objective lens? In what relative position is the slide inserted in the carrier? Why?

(c) If the image formed by the projector is too large for the screen should you move the projector closer to the screen or farther away from it? Why? What further adjustment would be necessary?

(d) The object is 16 mm. high and 50 mm. from the lens. If the screen is 6 metres away, what is the height of the image?

CHAPTER 21 EXPERIMENTS ON LIGHT

EXPERIMENT 1

To study the characteristics of an image produced by a pin-hole camera. (Ref. Sec. IV:4)

Apparatus

Pin-hole camera (Fig. 16:3), one large candle, one small candle.

Method

1. With the adjustable section of the camera held stationary so that the ground-glass screen is a fixed distance from the pin-hole, observe the size and other characteristics of the image of the candle placed at some distance from the camera. Move the camera closer to the candle and note the size of the image.
2. Holding the camera a fixed distance from the candle, note the size of the image. Move the adjustable section thereby decreasing the distance of the screen, and hence of the image, from the pin-hole, and again note the size of the image.
3. With the adjustable section held stationary as in step 1, observe the size of the image produced by first the large, and then the small candle at a fixed distance from the camera.
4. If possible, enlarge the pin-hole and note the effect on the brightness and sharpness of the image.

Observations

Record carefully the observations for each of the previous steps.

Conclusions

1. State the characteristics of the image.
2. What effect did each of the following have on the size of the image:
   (a) decreasing object distance?
   (b) decreasing image distance?
   (c) decreasing size of object?
3. Establish the formula: $\frac{H_i}{H_o} = \frac{D_i}{D_o}$
4. On what does the brightness of the image and its sharpness of definition depend? Explain fully.

Questions

1. Why do we get an image of the candle and not an image of the pin-hole?
2. What image would be obtained if the hole were increased in size until it has a diameter of 1 in. or more? Why?

EXPERIMENT 2

To establish the laws of reflection. (REF. SEC. IV:9)

Apparatus

Plane mirror, pins, sheet of paper, tack board, ruler, protractor.

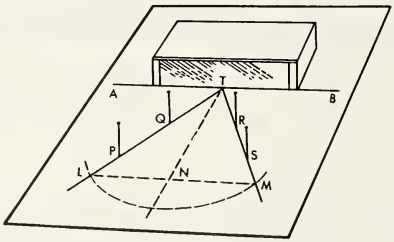


Fig. 21:1

Method

A. Demonstration Experiment—Optical Disc Method (Sec. IV:9).

B. Student Experiment—Pin Method.

1. Draw a straight line *AB* (Fig. 21:1). Place the mirror perpendicular to the paper so that its back edge is along this line.
2. Place pins at *P* and *Q* about 2 in. apart so that the line *PQ* strikes the mirror obliquely.
3. Look into the mirror with one eye at the level of the paper and line up the images of *P* and *Q*. Insert pins *R* and *S* in line with these images.
4. Mark the position of all the pins. Remove the mirror and the pins. Draw the lines *PQ* and *RS*. Produce these lines until they meet at *T*. Through *T* draw *TN* perpendicular to *AB*. With a protractor measure angles *PTN* and *STN*.
5. Repeat, with other positions of the pins.

Observations

1.

OBSERVATION No.	ANGLE OF INCIDENCE ∠ PTN	ANGLE OF REFLECTION ∠ STN
1.		
2.		
3.		

2. When the incident ray is on the plane of the paper where are the reflected ray and the normal found?

Conclusions

1. State the two Laws of Reflection.
2. Define, and label on your diagram: incident ray, reflected ray, point of incidence, normal, angle of incidence, angle of reflection.

Questions

1. If a polished piece of metal were used as the mirror in the above experiment, where would *T* be found? Why?
2. Add an observer's eye to the diagram and trace the path of the rays to the eye.

EXPERIMENT 3

To study the position and characteristics of the image in a plane mirror. (Ref. Sec. IV:11)

Apparatus

Plane mirror, two wooden pegs, paper, ruler, protractor.

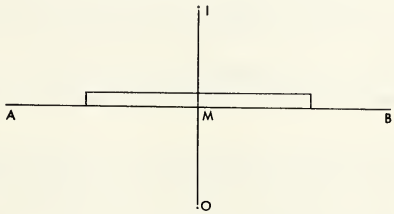


Fig. 21:2

Method

1. Draw a straight line *AB* in the middle of the sheet of paper. Place a plane mirror perpendicular to the paper, so that its reflecting surface is on *AB*.
2. Place the object (wooden peg) about 3 in. in front of the mirror. Mark its position *O*.
3. Look into the mirror to see the image of this object, and using the second wooden peg as a finder place it exactly where the image appears to be. This can be done quite accurately by using the method of parallax. That is, look into the mirror at the image, and over the top of the mirror at the finder. Adjust the position of the latter so that when you move your eye from side to side there is no relative movement between the finder and the image. Mark the position of the image *I*. Compare the size of the image to the size of the object.

4. Remove the mirror. Join OI and let the line cut AB at M. Measure the lengths of OM and IM, and measure the sizes of the angles at M.
5. Repeat for other positions of the object.
6. Look at yourself in a mirror and raise your left hand. Note what you see.

Observations

1.

OBSERVATION NUMBER	DISTANCE OF OBJECT OM	DISTANCE OF IMAGE IM	SIZE OF ANGLES AT M
1.			
2.			
3.			

2. How does the size of an object and its image compare?
3. Which hand appeared to be raised in the mirror? What term applied to the image describes this phenomenon?
4. What kind of image is it?

Conclusions

1. State your conclusion relating to the position of an image in a plane mirror.
2. Summarize the characteristics of such an image.
3. Define or explain: parallax, lateral inversion, virtual image.

Questions

1. How could you locate geometrically the position of the image of an object in a plane mirror? Show this by a diagram.
2. Include in the diagram an eye, and show the path of the light rays whereby the eye sees the image.

EXPERIMENT 4

To show the location of images produced by two plane mirrors at right angles. (REF. SEC. IV:13)

Apparatus

Two plane mirrors, four wooden pegs, paper, ruler, protractor.

Method

Repeat parts 1, 2 and 3 of experiment 3 using two plane mirrors placed at right angles to each other.

Observations

Describe the number and location of the images.

Conclusion

Construct a diagram to show how the images were obtained.

Questions

1. Add an observer's eye to the above diagram and trace the path of the rays to the eye.
2. Determine experimentally how many images are obtained when the mirrors are inclined at 60°, at 45°, etc. Use your results to verify the formula:

$$\text{Number of images} = \frac{360°}{\text{angle of inclination}} - 1$$

EXPERIMENT 5

To study the action of a concave mirror, and to determine its focal length (f). (Ref. Sec. IV:14)

Apparatus

Optical bench, concave mirror, candle, screen.

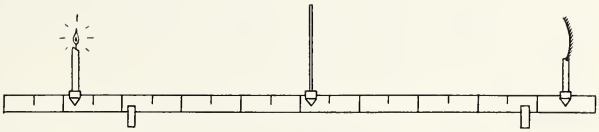


Fig. 21:3

Method

A. Demonstration Experiment—Optical-Disc Method (Sec. IV:14).

B. Student Experiment—Optical-Bench Method.

1. Mount the concave mirror and screen on the optical bench. Hold the mirror so that rays from the sun fall directly upon it. Failing that, hold it so that rays from a candle held at the opposite end of the room fall upon it. Focus the image on the screen. To do this move the screen until the image is clear and sharply defined.
2. Measure the distance of the image from the vertex of the mirror.

Observations

1. What is observed when parallel incident rays are reflected from the mirror?
2. Describe the image obtained when the object is at infinity.
3. What is the distance of the image from the vertex of the mirror?

Conclusions

1. What effect does a concave mirror have on light rays incident upon it?
2. Define: principal focus, focal length.

Questions

1. Why may a concave mirror be called a converging mirror?
2. Why did we use an infinitely distant object in the above experiment?

EXPERIMENT 6

To study the images produced by a concave mirror.
(REF. SEC. IV:15)

Apparatus

Optical bench, concave mirror of known focal length, candle, screen, finder.

Method

1. Place the candle at more than twice the focal length (f) from the mirror. Locate the image on the screen and state its characteristics.
2. Repeat the above for two or three other positions of the candle as it is gradually moved nearer to the principal focus of the mirror.
3. Place the candle between the principal focus and the mirror. Look into the mirror to see the image. Note its characteristics and locate its position by the method of parallax using the finder.

Observations

Observation Number	Position of Object	Position of Image	Characteristics of Image		
			Size	Attitude	Kind
1.					
2.					
3.					

Conclusions

1. Where may an object be placed so that a real image of it is produced by a concave mirror?
2. Describe the changes in position and characteristics of the image as the object is gradually moved from infinity to the principal focus of a concave mirror.
3. Describe the position and characteristics of the image when the object is between the principal focus and the mirror.

Question

Make accurate scale diagrams to locate the images for the above positions of the object.

EXPERIMENT 7

To study the images produced by a convex mirror.
(REF. SEC. IV:16)

Apparatus

Optical bench, convex mirror, candle, finder.

Method

Using the candle at three different positions from the mirror, locate the image each time by the method of parallax, and state its characteristics.

Observations

Observation Number	Position of Object	Position of Image	Characteristics of Image		
			Size	Attitude	Kind
1.					
2.					
3.					

Conclusions

1. What kind of image is produced by a convex mirror?
2. Describe the position and characteristics of the images produced by a convex mirror for all positions of the object.

Questions

1. How would you find the focal length of a convex mirror?
2. Why may such a mirror be called a diverging mirror?
3. Construct a geometric diagram to locate the image of an object produced by a convex mirror.

EXPERIMENT 8

To measure the refractive index of glass. (Ref. Sec. IV: 21, 23)

Apparatus

Rectangular block of plate glass with one pair of opposite edges polished, sheet of paper, tack board, pins, geometrical instruments.

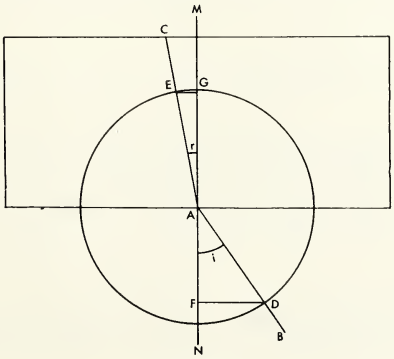


Fig. 21:4

Method

1. Lay the sheet of paper on the tack board. Place the glass block on the sheet of paper. Outline its position carefully.
2. Stick a pin A upright in the paper, near the centre of one edge of the glass and touching it.
3. Stick a second pin B upright in the paper about 2 in. from A so that a line joining the two meets the glass obliquely.
4. Look through the block, line up the images of A and B and insert pin C against the opposite edge of the glass block so that it and the images of A and B appear in a straight line. Mark the position of each pin.
5. Remove the block and pins and draw BA, and AC. Draw the normal MN at A. With centre A describe a circle to cut AB at D and AC at E. From D and E draw perpendiculars DF and EG to the normal MN.
6. Measure the distances DF and EG and calculate the value of $DF \div EG$. With a protractor measure the angles of incidence ($\angle BAF$) and of refraction ($\angle CAG$). Using a table of sines calculate $\sin \angle i \div \sin \angle r$.
7. Repeat for several other positions of the pins and arrange your results in the following observation table.

Observations

Obs. No.	DF	EG	DF/EG	$\angle i$	$\angle r$	$\sin \angle i/\sin \angle r$
1.						
2.						
3.						
4.						
	Average			Average		

Conclusion

Define: Index of Refraction.

Questions

1. Compare your experimental value with the theoretical value (table p. 199). Calculate your percentage error.
2. Which way does light bend on entering obliquely a different medium of greater optical density? Why?

EXPERIMENT 9

To trace the path of light through a glass plate with parallel sides. (REF. SEC. IV:24)

Apparatus

Same apparatus as in experiment 8.

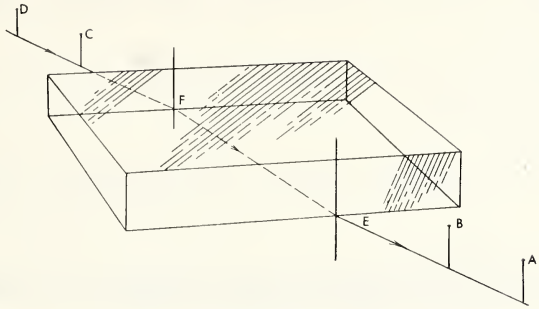


Fig. 21:5

Method

1. Lay the sheet of paper on the tack board. Place the glass block on the sheet of paper. Outline its position carefully.
2. Stick two pins *A* and *B* upright in the paper, about 2 in. apart, so that a line joining them (the incident ray) strikes the glass obliquely.
3. Look through the block, line up the images of *A* and *B* and insert pins *C* and *D* about 2 in. apart so that they and the images of *A* and *B* appear in a straight line. Mark the position of each pin.
4. Remove the block and pins. Join *AB* and produce it to meet the block at *E*. Join *CD* and produce it to meet the block at *F*. Join *EF*. On your diagram label the incident, refracted, and emergent rays.
5. Draw the normals at *E* and *F*. Measure the angle of incidence at *E*, and the angle of emergence at *F*.
6. Repeat the experiment for angles of incidence of different sizes.

Observations

1. In what direction relative to the normal does the light ray bend on entering the glass at *E* and on leaving it at *F*?
2.

	1.	2.	3.
Angle of incidence at *E* =			
Angle of emergence at *F* =			

Conclusions

1. How does the angle of incidence compare with the angle of emergence?

2. What relationship exists between the directions of the incident and emergent rays?
3. Describe the path of a light ray through a glass plate with parallel sides.

Explanation

Explain the observed bending of the light ray on entering and on leaving the glass.

Question

What factors affect the amount of lateral displacement of the emergent ray?

EXPERIMENT 10

To illustrate the apparent change in depth due to refraction of light at a plane surface. (REF. SEC. IV:24)

Apparatus

Tall beaker, two pins, water.

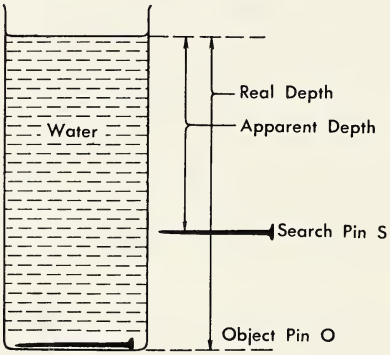


Fig. 21:6

Method

1. Place a pin at the bottom of the beaker and pour in water to a depth of about 15 cm. This pin is the object, *O*.
2. Hold the search pin, *S*, horizontally outside the beaker. View from directly above and adjust the position of the search pin until there is no parallax between it and the image of the object pin.
3. Determine the distance of the object pin, and of the search pin from the surface of the water, thus finding the real and apparent depths.
4. Repeat the experiment using different depths of water.
5. Tabulate your observations and determine the average value for real depth ÷ apparent depth.

Observations

Observation Number	Real Depth	Apparent Depth	Real Depth ÷ Apparent Depth
1.			
2.			
3.			
4.			

Conclusions

1. Construct a diagram to show the path of the light rays from the immersed object to an observer's eye.
2. Why is the apparent depth always less than the real depth?
3. Compare the value obtained by dividing the real depth by the apparent depth to the index of refraction of water (table, page 199).

Questions

1. In step 3 of the method, why must the measurements be made on the outside of the beaker?
2. If the water in the above experiment were replaced with an optically denser liquid, e.g., carbon tetrachloride, what effect would this have on the apparent position of the object? Why? Try the experiment.

EXPERIMENT 11

To show deviation produced by refraction through a prism. (Ref. Sec. IV:25)

Apparatus

A 60° prism, sheet of paper, tack board, four pins, geometrical instruments.

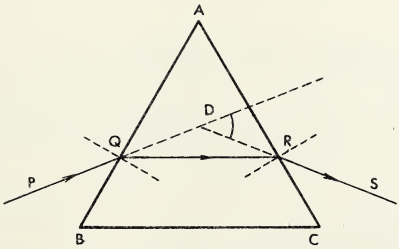


Fig. 21:7

Method

A. Demonstration Experiment—Optical-Disc Method (Sec. IV:25).
B. Student Experiment—Pin Method.

1. Lay the sheet of paper on the tack board. Place the prism on the paper. Outline its position carefully. Label its vertices A, B and C.
2. Stick two pins P and Q upright in the paper about 2 in. apart so that Q is touching the prism, and a line joining them (the incident ray) strikes the surface of the prism, AB, obliquely.
3. Look through the prism on the side AC. Line up the images of P and Q and insert pins R and S about 2 in. apart with R touching the prism, so that they and the images of P and Q appear in a straight line. Mark the position of each pin.
4. Remove the prism and the pins. Join PQ, QR and RS. Label the incident, refracted and emergent rays.
5. Extend PQ and SR to meet at D. Measure the size of $\angle D$ (angle of deviation).
6. Construct the normals at Q and R. Measure the angle of incidence and the angle of emergence.
7. Repeat on separate diagrams for three other angles of incidence, including the special case where the angle of incidence is equal to the angle of emergence.

Observations

1. Which way does the light ray bend
   (a) on entering the prism?
   (b) on leaving the prism?
2.

OBS. NO.	ANGLE OF INCIDENCE	ANGLE OF DEVIATION	ANGLE OF EMERGENCE
1.			
2.			
3.			
4.			

Conclusions

1. Describe the path of a light ray through a prism.
2. Describe how the angle of deviation varies as the angle of incidence is changed.
3. What is the relationship of the angle of incidence to the angle of emergence when the deviation is a minimum?

Questions

1. Draw a diagram showing a ray of light passing through the prism at the position of minimum deviation.
2. What factors affect the amount of deviation produced by a prism?

EXPERIMENT 12

To study the action of a convex and a concave lens, and to determine their focal lengths. (REF. SEC. IV:28, 29)

Apparatus

Optical bench, convex lens, concave lens, candle, screen, finder.

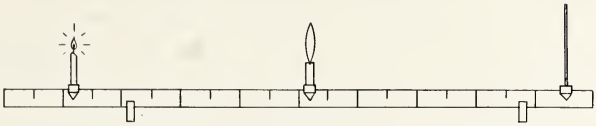


Fig. 21:8

Method

A. Demonstration Experiment—Optical-Disc Method (Sec. IV:29).
B. Student Experiment—Optical-Bench Method.

1. Mount the convex lens and screen on the optical bench. Hold the lens so that rays of light from the sun, or from a distant candle, fall directly upon it. Focus the image on the screen.
2. Measure the distance of the image from the optical centre of the lens.
3. Repeat using the concave lens. In this case, in order to see the image, it is necessary to look into the lens toward the object. The position of the image can be determined by the method of parallax with the aid of the finder.

Observations

1. What is observed when parallel incident rays are refracted through (a) the convex lens, (b) the concave lens?
2. Describe the image obtained when the object is at infinity using (a) the convex lens (b) the concave lens.
3. What is the distance of the image from the optical centre of the lens?

Conclusions

1. What effect do (a) a convex lens, (b) a concave lens, have on light rays incident upon them?
2. Define: principal focus, focal length.

Questions

1. What other name may be given to (a) a convex lens, (b) a concave lens? Why?
2. Why did we use an infinitely distant object in the above experiment?

EXPERIMENT 13

To study the images produced by a convex lens.
(Ref. Sec. IV:30)

Apparatus

Optical bench, convex lens of known focal length, candle, screen, finder.

Method

1. Place the candle at more than twice the focal length (f) from the lens. Locate the image on the screen and state its characteristics.
2. Repeat the above for two or three other positions of the candle as it is gradually moved nearer to the principal focus of the lens.
3. Place the candle between the principal focus and the lens. Look into the lens to see the image. Note its characteristics and locate its position by the method of parallax using the finder.

Observations

Observation Number	Position of Object	Position of Image	Characteristics of Image		
			Size	Attitude	Kind
1.					
2.					
3.					

Conclusions

1. Where may an object be placed so that a real image of it is produced by a convex lens?
2. Describe the changes in position and characteristics of the image as the object is gradually moved from infinity to the principal focus of a convex lens.
3. Describe the position and characteristics of the image when the object is between the principal focus and the lens.

Question

Make accurate scale diagrams to locate the images for the above positions of the object.

EXPERIMENT 14

To study the images produced by a concave lens.

(REF. SEC. IV:31)

Apparatus

Optical bench, concave lens, candle, finder.

Method

Using the candle at three different positions from the lens, locate the image each time by the method of parallax, and state its characteristics.

Observations

Observation Number	Position of Object	Position of Image	Characteristics of Image		
			Size	Attitude	Kind
1.					
2.					
3.					

Conclusions

1. What kind of image is produced by a concave lens?
2. Describe the position and characteristics of the images produced by a concave lens for all positions of the object.

Questions

1. How would you find the focal length of a concave lens?
2. Why may such a lens be called a diverging lens?
3. Construct a geometric diagram to locate the image of an object produced by a concave lens.

EXPERIMENT 15

To study the dispersion of white light into the spectrum.
(Ref. Sec. IV:36(a)

Apparatus

Projection lantern, single slit, converging-lens, prism, white cardboard screen.

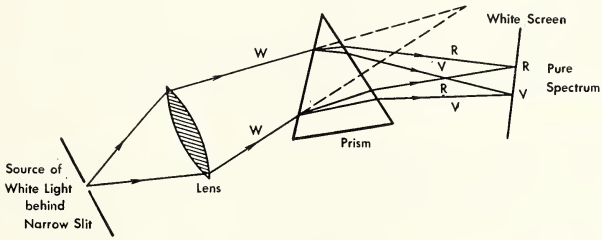


Fig. 21:9

Method

Direct a beam of light from the projection lantern on to the slit. Place the converging-lens in the light that diverges from the slit, and focus these rays on the screen at *A*. Place the prism in the path of the beam and note what happens to the light. Rotate the prism so that the emergent beam sweeps to and fro. Adjust the position of the prism until the emergent beam is as near as possible to *A*. The prism is now in the position of minimum deviation. Move the screen into the path of the beam and adjust its position until the light which falls on it is in clear focus.

Observations

1. What happened to the beam of light on passing through the prism?
2. Name the colours of the spectrum that you see.
3. Which coloured rays are deviated least, and which most, by the prism?

Explanation

1. Why is light deviated on passing through the prism?
2. Why are different colours deviated different amounts?
3. Which is deviated the least? Why? Which the most? Why?

Conclusions

1. What must white light consist of?
2. What is meant by dispersion of white light?

Questions

1. What would be observed if a sensitive heat detector were placed just beyond the red end of the spectrum? Why?
2. What would be observed if a fluorescent material (*e.g.*, anthracene), were placed just beyond the violet end of the spectrum? Why?

EXPERIMENT 16

To recombine the colours of the spectrum into white light.
(REF. SEC. IV:36(b)

Apparatus

As in experiment 15, second prism identical to one used there, second converging lens, Newton's colour disc, rotating-machine.

Method

1. With apparatus arranged as in experiment 15, place the second prism with its refracting edge in the opposite position to that of the first. Move the screen to catch the image. Note what is obtained.
2. With apparatus arranged as in experiment 15, place the second converging-lens in the spectrum. Move the lens until the image is brought to a focus on the screen. Again note what is observed.
3. Examine Newton's colour disc. Place on the rotator. Strongly illuminate it with white light from the projection lantern. Rapidly rotate it. Note the effect obtained.

Observations

Describe carefully what is observed in each part above. Include diagrams.

Conclusion

How may the colours of the spectrum be combined to form white light?

Explanation

1. Why did the reversed prisms and the converging-lens re-form white light?
2. Why did Newton's disc appear white when rapidly rotated?

Question

How could a concave mirror be used to recombine the colour of the spectrum?

EXPERIMENT 17

To study the spectra of a few common elements.
(Ref. Sec. IV:39)

Apparatus

Direct-vision spectroscope, Bunsen burner with monochromatic flame attachment, sodium, calcium and lithium salts; electrical discharge tubes containing neon, nitrogen and hydrogen, induction coil, source of direct current.

Method

1. Place a sample of the sodium salt in the attachment on the burner. Light the burner and heat the salt. Observe the flame through the spectroscope. Repeat for the other salts.
2. By means of the induction coil send a high-voltage discharge of electricity through the tube containing neon. Observe the discharge through the spectroscope. Repeat using the tubes containing the other gases.

Observations

Describe the spectra obtained and compare with those given in Fig. 19:6.

Conclusion

How is the spectrum of an element obtained?

Questions

1. What is meant by spectrum analysis?
2. What are some of its advantages?

EXPERIMENT 18

To study colour in natural objects (a) opaque (b) transparent.
(Ref. Sec. IV:40)

Apparatus

As in experiment 15, red, yellow and blue cardboard screens; red, yellow and blue glass filters.

Method

Produce a pure spectrum as outlined in experiment 15.

1. Replace the white screen by the coloured screens in turn. Note any change in the appearance of the spectrum each time.

2. With the white screen in place, insert each of the coloured filters in the path of the beam. Note any change in the appearance of the spectrum each time.
3. Repeat 2 using both the yellow and blue filters in the path of the light beam. Note the colour of the light obtained.
4. Repeat 2 using all three filters (red, yellow and blue) in the path of the beam. Note what is obtained.

Observations

Describe carefully all that is observed. Represent your observations by means of simple diagrams.

Explanation

Account for each of the observations.

Conclusion

What is the cause of colour in (a) opaque (b) transparent objects?

Questions

1. An object is viewed in white light and appears red. Why?
2. A blue filter is placed between the source of white light and the same object. What will be the appearance of the object? Why?

EXPERIMENT 19

To study the action of the astronomical refracting telescope. (REF. SEC. IV:48)

Apparatus

Optical bench, convex lenses of 20 cm. and 5 cm. focal lengths.

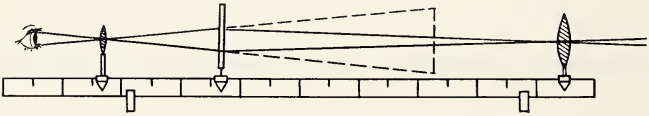
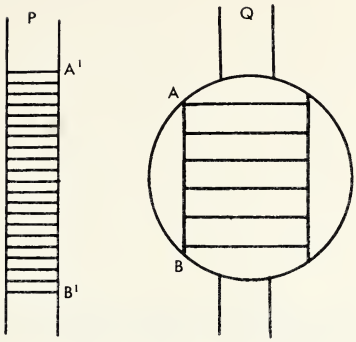


Fig. 21:10

Method

1. Place the two convex lenses on the optical bench so that the distance between them is equal to the sum of their focal lengths (25 cm.). Using the convex lens of shorter focal length as the eyepiece and the other as the objective, look through the lenses at distant objects.



2. Construct two similar scales, P and Q, with divisions about 1 in. apart and place them near each other at the far end of the room. (Similar scales may be drawn on the blackboard if this is preferred.) Look through the telescope at the scale Q with one eye, and at the same time look at scale P with your other eye.
   Have your partner mark the point on scale P which is level with the uppermost division of Q observed through the telescope. Repeat for the lowest division observed. Compare the number of complete divisions, AB, observed through the telescope with the number of corresponding scale divisions, A^1B^1, observed directly. Determine the magnifying power of the telescope.

Observations

1. What is observed when distant objects are viewed through the telescope?
2. How many complete scale divisions were observed
   (a) through the telescope? $AB =$
   (b) directly? $A^1B^1 =$

Calculations

1. Determine the magnifying power of the telescope from the above observations.
2. Compare this value to that obtained by dividing the focal length of the objective by the focal length of the eyepiece.

Conclusions

1. What is the action of an astronomical telescope?
2. What is the magnifying power of this telescope?

Questions

1. By means of a diagram trace the paths of the light rays by which the observer sees the object through this telescope.
2. What disadvantage has this telescope for viewing terrestrial objects? How could this disadvantage be overcome?

UNIT V

MAGNETISM and ELECTRICITY

Star Newspaper Service

Seconds Before the Photograph was Taken, Lightning Caused this Fire. Explain Exactly What Happens

CHAPTER 22 MAGNETISM

V : 1 INTRODUCTION TO MAGNETISM

The study of magnetism began with the observation of the power of attraction of lodestone for iron. Lodestone is the mineral **magnetite**, an oxide of iron, which was first discovered in the province of Magnesia (from which the name magnet was derived) in Asia Minor. Deposits of this mineral are found in many other parts of the world including large areas of Canada and the United States.

The original discovery of magnetite is recorded in an ancient legend which tells of a Cretan shepherd whose iron-tipped crook was so strongly drawn to the earth that he dug to find the cause. Fables tell of magnetic rocks covered on their seaward sides with nails drawn from passing ships, and of iron statues supported in mid air.

For centuries men have been intrigued by the phenomena of magnetic properties. In the writings of Lucretius, a Roman who died in 52 B.C., the following reference is found:

> "And iron filings in the brazen bowls seethe furiously; when underneath was set the magnet stone."

It was in the period of the Renaissance when William Gilbert, physician to Queen Elizabeth I of England, published his famous and hitherto unequalled book entitled *De Magnete*. In his book Gilbert emphasized the importance of scientific method, and of arriving at conclusions only after careful experiment. He dedicated his work "to you alone, true philosophers, ingenious minds, who not only in books but in things themselves look for knowledge."

De Magnete laid the foundation of magnetic science. It described in detail a wide variety of experiments in magnetism. The book proved, however, to be too much in advance of its time and was soon forgotten. For the next hundred and fifty years there was little progress, but in the latter part of the eighteenth century magnetism began to be recognized as the exact science that it has become today.

V : 2 SOME PROPERTIES OF MAGNETS

When an iron bar is stroked with a natural magnet, the iron itself becomes capable of attracting other pieces of iron or steel. It has become an artificial magnet (Fig. 22:1). If this magnet is brought near to a number of different materials in succession, it is found that only a few of these, called **magnetic substances**, are attracted. Among these are iron, nickel, cobalt and a few special alloys. The materials which are not attracted are said to be **non-magnetic** (Chap. 31, Exp. 1).

If a bar magnet is rolled in iron filings, the filings are seen to be attracted in large clumps around the ends of the magnet (Fig. 22:2). These points at which the magnetic force is concentrated are called the **poles** of the magnet (Chap. 31, Exp. 2).

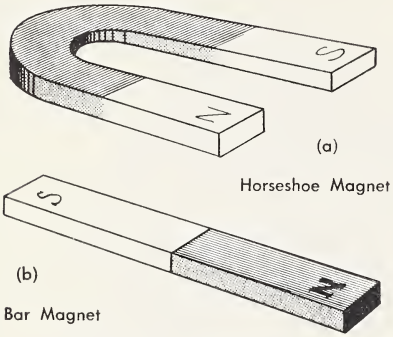


Fig. 22:1 Artificial Magnets
(a) A Horseshoe Magnet.
(b) A Bar Magnet.

A magnet which is suspended freely from a non-magnetic stand will always come to rest with its axis along a line running approximately north-south. The same end of the magnet will always point towards the north. This is designated the north-seeking (N-pole) of the

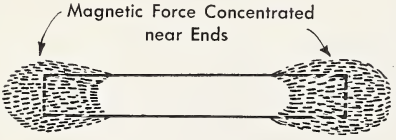


Fig. 22:2 Iron Filings Clustered Around the Poles of a Bar Magnet.

magnet and the other end is the south-seeking pole (S-pole) (Chap. 31, Exp. 3).

If the N-pole of the suspended magnet is now approached by the N-pole of another magnet, the poles will be observed to move farther apart (Fig.

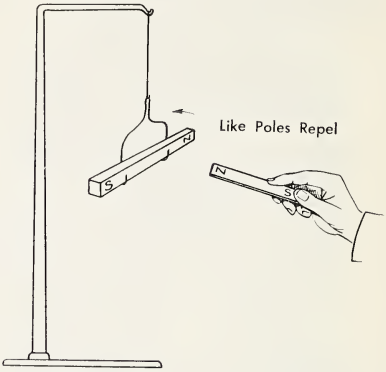


Fig. 22:3 Demonstrating the Law of Magnetism.

22:3). This motion is caused by a force, here one of repulsion. When the S-pole of the suspended magnet is approached by an N-pole of another magnet they will be attracted to each other. From such observations we may conclude that:

like magnetic poles repel; unlike magnetic poles attract.

This is called the **Law of Magnetism** (Chap. 31, Exp. 4).

V : 3 THE EARTH AS A MAGNET

In the previous section it was shown that a suspended magnet always comes to rest along a north-south line. The magnet behaves in this way because the earth itself possesses a magnetic field as if it contained a huge bar magnet lying nearly parallel to its axis (Fig. 22:4). Why is the end of the magnet that points north labelled *S*?

The magnetic north pole is located about 1400 miles south of the geographic north pole in the extreme north-central part of Canada.

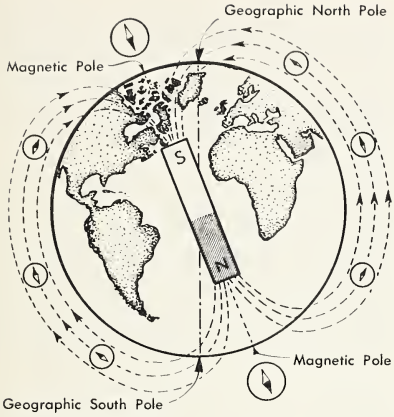


Fig. 22:4 The Earth's Magnetic Field.

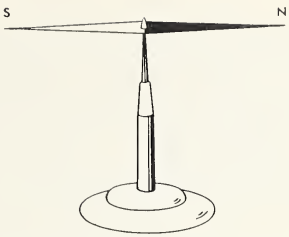
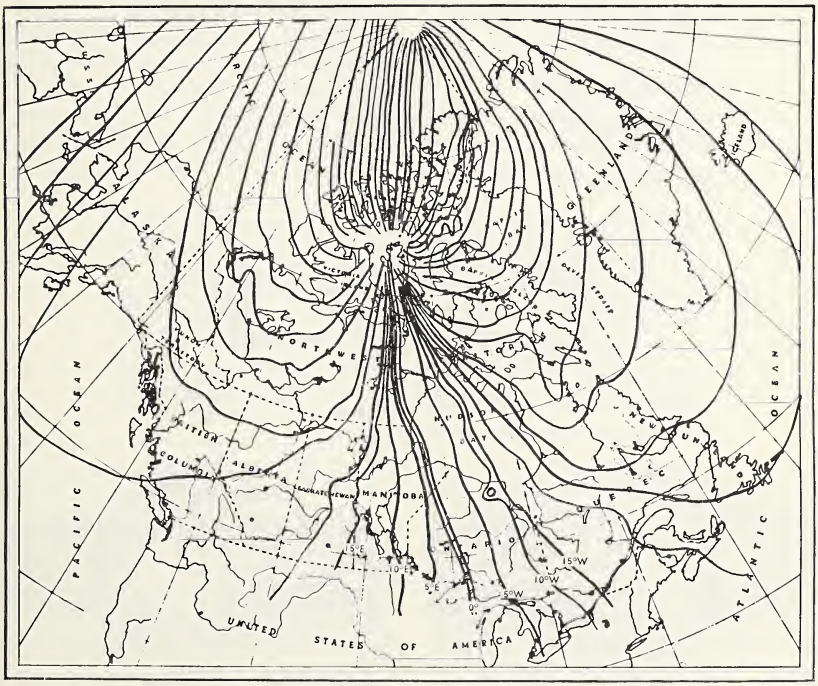


Fig. 22:5 Demonstration Magnetic Compass.

The modern **magnetic compass** (Fig. 22:5) consists of a magnetized steel needle suspended on a point so that it is free to move in a horizontal plane. The N-pole of the compass will point



Outline Map Courtesy of Dept. of Mines and Technical Surveys.

Fig. 22:6 Map of Canada Showing Points of Equal Declination, 1955.

always to the earth's magnetic north pole. The angle between the true north and the direction in which the compass points is called the **angle of declination** (Fig. 22:6). It is evident that the angle of declination will vary with position on the earth's surface. A navigator must determine its value from charts in order to find true north from the compass bearing at his position. The declination at Toronto, Ontario, was approximately 7° west in 1955. This indicates that the angle between the lines drawn from Toronto to the geographic north pole and to the magnetic north pole is 7°, and the magnetic line is west of the line to the geographic pole. The magnetic north pole shifts its position slowly westward, and its exact location must be resurveyed frequently in order to correct charts for navigation purposes.

V : 4 THE MAGNETIC FIELD

The effect of a magnet is noticeable over a considerable space surrounding it. This can be demonstrated by placing a compass-needle at a number of positions at varying distances from the magnet and observing the direction in which the needle points. The space surrounding a magnet in which its magnetic influence can be detected is known as the **magnetic field** of the magnet.

Magnetic fields were studied by Gilbert in the sixteenth century, but Michael Faraday (1791-1867) showed that they could be best described and interpreted by means of magnetic maps made up of a series of lines known as lines of force. A **line of force** may be defined as the path that would be travelled by a free N-pole if at liberty to move in a magnetic field. By specifying the movement of an N-pole in our definition we obtain the conventional direction for the lines of force, i.e., from the N-pole of the magnet, which would repel the free N-pole, to the S-pole of the magnet which would attract it.

An effective method of demonstrating the disposition of the lines of force about a magnet is described in chapter 31,

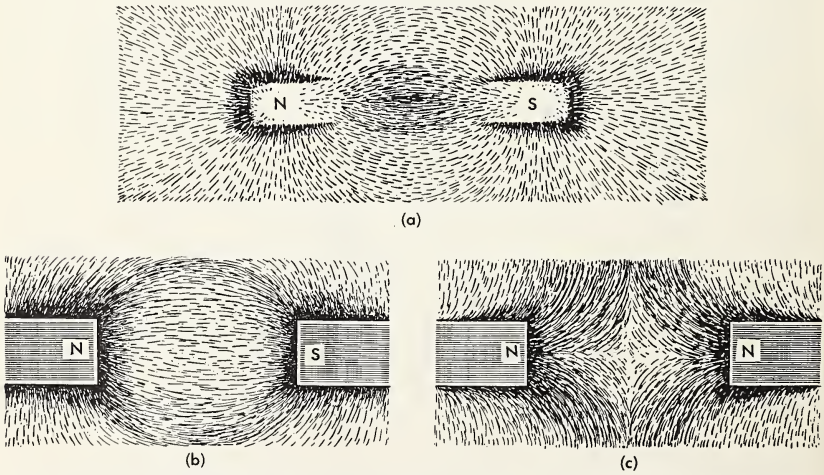


Fig. 22:7 The Magnetic Field about (a) A Bar Magnet (b) Unlike Poles (c) Like Poles.

experiment 5. Some examples of magnetic maps obtained in this way are shown in Fig. 22:7.

The properties of lines of force as shown on these maps may be summarized as follows:

1. Lines of force form closed curves, leaving the N-pole of the magnet, proceeding through space to the S-pole, and completing their path through the magnet. The apparently loose ends shown in the diagrams are actualiy parts of complete lines linking the poles of the magnets.
2. Lines of force never cross but tend to repel each other, thus spreading farther and farther apart as they leave the N-pole of the magnet.
3. Lines of force behave like stretched elastic bands, tending to contract and thus to shorten their paths.
4. The concentration of the lines of force determines the strength of the magnetic field at any point. Thus the field is strongest close to the poles of the magnet.

The property of a substance that allows magnetic lines of force to pass through it is called **permeability**. Substances such as soft iron and permalloy, an alloy of nickel and iron, which allow lines of force to pass through them readily are said to have a high permeability. For this reason these materials are used where a strong magnetic field is desirable as in the electromagnet (Sec. V:50) and the galvanometer (Sec. V:53).

V : 5 THE ANGLE OF INCLINATION

In section V:3 the earth was described as possessing a magnetic field of its own. It is the horizontal component of this field that activates the magnetic compass. The exact direction of the magnetic lines of force may be determined by the use of a **dipping needle.** This consists of a magnetized needle that is free to turn in a vertical plane, and a protractor to measure its inclination from the horizontal (Fig. 22:8). The plane of this needle must be adjusted so that it is parallel to the direction indicated by a compass. The instrument will then indicate the direction of the lines of force. At the magnetic poles the needle will

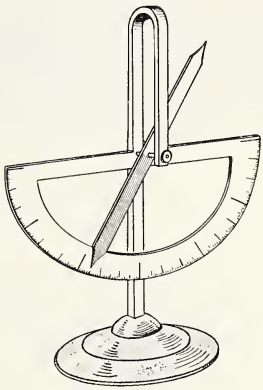
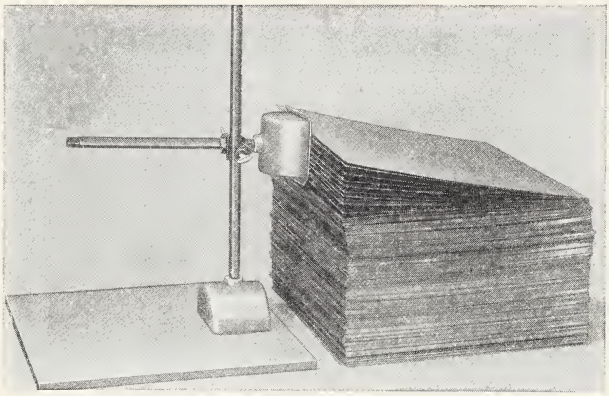


Fig. 22:8 Dipping Needle.

stand vertically and the reading on its protractor will thus be 90°. At the magnetic equator the needle will be horizontal and the angle of inclination or dip will be 0°. Other locations on the earth's surface will give readings between these extremes. At Toronto the angle of inclination is about 74°.

V : 6 INDUCED MAGNETISM

An unmagnetized piece of soft iron will not attract iron filings. If, however, we bring it near the pole of a bar magnet, the iron will become a magnet and exhibit powers of attraction. When the bar magnet is removed the soft iron will lose its magnetic properties very rapidly. The iron is said to have been **magnetized by induction.** If the S-pole of the bar magnet approaches the soft iron it can be shown that the end of the iron



A Permanent Magnet Being Used to Separate Metal Sheets.

Canadian General Electric

nearest the magnet becomes an N-pole and the other end becomes an S-pole (Chap. 31, Exp. 6).

If a bar of soft iron is held at the angle to the earth's surface that is indicated by a dipping needle and one end is tapped sharply with a hammer, it can be demonstrated that the iron has become a weak magnet (Chap. 31, Exp. 7). Thus we see that even the weak magnetic field of the earth is capable of causing magnetism by induction.

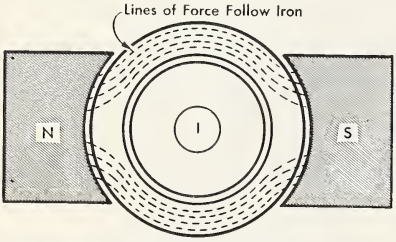


Fig. 22:9 Magnetic Shielding. Lines of Force Follow the Soft Iron Ring. Instrument I, in centre, is Unaffected by Magnetic Field.

It may be readily understood then, that magnetic substances such as the iron parts of machines, steel frameworks of buildings, hulls of ships, etc. may become magnetized by induction. The magnetic fields from these structures may seriously affect delicate measuring instruments such as watches and compasses.

In order to protect such instruments they are frequently enclosed in a **magnetic shield** of some highly permeable metal. The lines of force pass through the shielding material more readily than through the space enclosed by it (Chap. 31, Exp. 8), and so the instruments operate free from magnetic disturbance. The effect of magnetic shielding is illustrated in Fig. 22:9.

Induced magnetism plays an important part in many of the devices that will be studied in later chapters of this unit.

V : 7 A THEORY OF MAGNETISM

If a piece of iron wire magnetized as in experiment 9, chapter 31, is subjected to continued division and sub-division, each piece will be found to be a small magnet possessing an N-pole and an S-pole (Chap. 31, Exp. 10). When these pieces finally become too small for further division, we may imagine the process to be continued until finally the

molecule of the iron is reached. Thus each molecule would possess its own N- and S-pole of equal strength. We may then reason that all magnetic substances are composed of molecules that are tiny magnets in themselves (Chap. 31, Exp. 11).

Using this theory the unmagnetized state is accounted for by the random

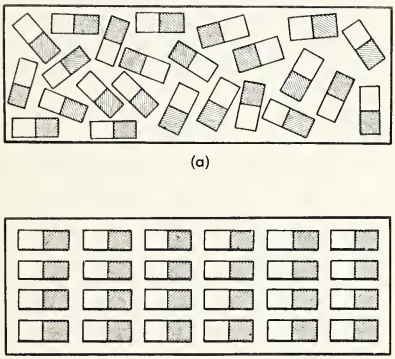


Fig. 22:10 The Theory of Magnetism (a) Unmagnetized State (b) Magnetized State.

distribution of millions of molecular magnets in the bar (Fig. 22:10a). The haphazard arrangement of N- and S-poles neutralizes their effect and no external magnetism is evident. When the bar is stroked with the N-pole of a magnet the S-poles of the molecular magnets are attracted in the direction of the stroking magnet and the molecules become aligned as shown in Fig. 22:10b. At the end of the bar last touched by the N-pole of the magnet there will be many S-poles of the molecular magnets and thus it will act as the S-pole of our new magnet. The opposite end, having many molecular N-poles will be the new N-pole. In the central region of the bar the N- and S-poles of the molecules will again neutralize each other so that we can now account for the concentration of magnetic properties at the poles of the magnet.

This molecular theory of magnetism provides a simple explanation of many magnetic phenomena. The fact that there are the same numbers of unbalanced N- and S-poles at either end of a magnetized iron bar means that the poles of a bar magnet will be equally strong. A section taken across the magnetized bar will expose an equal number of N- and S-poles showing that equal and opposite poles will be produced on breaking the magnet. **Saturation effect**, i.e., a magnetic substance can be magnetized only up to a certain strength is clearly due to the fact that when all molecular magnets have been drawn into line there can be no further increase in magnetic strength. The loss of magnetism due to rough handling or heat is due to the disturbance of the molecules and a reversion to the random arrangement.

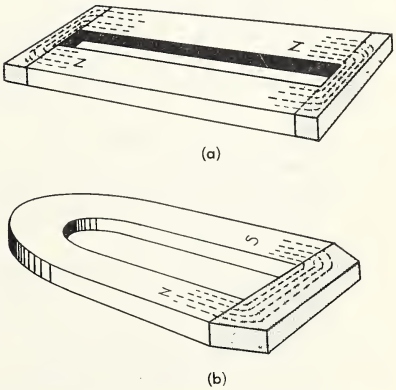


Fig. 22:11 Keepers (a) on Bar Magnets. (b) on a Horseshoe Magnet.

The mutual repulsion of the similar molecular poles at the ends of a magnet tends to push the molecular magnets out

of alignment and so slowly to destroy its magnetism. To prevent this, bar magnets are usually stored in pairs with opposite poles adjacent and a piece of soft iron, called a **keeper**, placed across each end as shown in Fig. 22:11. The keepers become magnetized by induction and their molecules tend to hold those of the magnet in alignment. A horseshoe magnet requires only one keeper as indicated.

A material which is readily magnetized but loses its magnetism rapidly, such as soft iron, is used to form **temporary magnets** used in electromagnets (Sec. V:50). The molecules of such substances are readily rearranged. Materials which have a more stable arrangement of molecules such as steel and alnico, an alloy of aluminum, nickel, and cobalt, are more difficult to magnetize, but tend to retain their magnetic properties much longer. Such substances are used to make the **permanent magnets** used in telephone receivers, galvanometers and other instruments.

V:8 QUESTIONS

A

1. (a) What is a natural magnet?
   (b) What is the common name of a natural magnet?

2. From the following list select those materials which are magnetic and those which are non-magnetic: glass, nickel, aluminum, wood, rubber, iron, copper, lead, cobalt, steel, zinc, tin.

3. (a) State the Law of Magnetism.
   (b) Explain how, with the aid of a compass-needle, you would determine which end of a magnet is the N-pole.

4. (a) Describe the simplest form of magnetic compass.
   (b) Explain why the N-pole of the compass points to the magnetic north pole of the earth.
   (c) Why doesn't a compass-needle point to the true north pole? Define angle of declination.

5. (a) Define line of magnetic force.
   (b) Draw the magnetic field about a bar magnet.
   (c) State three fundamental characteristics of these lines of force.

6. (a) Define angle of inclination or dip.
   (b) What would be the angle of inclination at (i) the magnetic north pole, (ii) the magnetic south pole and (iii) the magnetic equator?

7. (a) What is meant by magnetic induction?
   (b) By means of a labelled diagram show how you could induce magnetism into a nail so that the head is an N-pole.

8. (a) Define magnetic permeability.
   (b) What is "magnetic shielding"?
   (c) Where and why would such shielding be necessary?

9. (a) Describe how you could magnetize a steel needle.
   (b) How could a piece of steel wire be magnetized by a bar magnet without returning the magnet in a wide arc?

10. (a) Outline the theory of magnetism.
    (b) Use this theory to explain:
    (i) that a magnet when repeatedly cut gives sections that are magnets also.
    (ii) polarity of a magnet.
    (iii) that there is no magnetic power in the centre of a magnet.
    (iv) that magnetism is lost on heating or jarring a magnet.
    (v) magnetic induction.
    (vi) magnetic saturation.

(vii) the difference between temporary, and permanent magnets.

B

1. A rod of soft iron is held vertically and struck with a hammer.

(a) Describe how you would test whether the rod is magnetized.

(b) Which end should become an **S**-pole?

(c) Why strike it with a hammer?

2. How could you use a compass-needle to distinguish between a magnet and a magnetic substance?

3. (a) How could the lines of magnetic force of a horseshoe magnet be traced?

(b) Show by means of a diagram the pattern that you would expect to see.

4. A steel bar is repeatedly stroked from A to B with the **N**-pole of a bar magnet. A compass-needle is then placed near the end B of the steel bar. Make a diagram of the steel bar and compass-needle and label all poles.

5. How would you use a compass-needle to distinguish between three bars similar in shape and appearance if one is brass, the second is unmagnetized iron and the third is a magnet?

6. You are given two iron bars — one magnetized, the other not — and nothing else. Describe carefully how you could determine which is the magnet.

CHAPTER 23 ELECTROSTATICS

V : 9 INTRODUCTION TO ELECTROSTATICS

Every high-school student is familiar with many devices operated by electricity. However, this is electricity in motion, a comparatively recent scientific development. Early experiments in this field were confined to electricity at rest, or **static electricity**. The discovery of electricity is generally attributed to Thales of Miletus, one of the seven wise men of Greece, about 600 B.C. He learned that amber, a yellowish fossilized resin, when rubbed with a fabric would attract light objects. This knowledge remained an isolated fact of science for over two thousand years. From the beginning of the seventeenth century electrical science began to grow, and it is from the early experiments of such men as Gilbert and Gray in England, du Fay in France, and Franklin in America that many of our fundamental concepts of electricity have arisen. The study of electrostatics has paved the way for advancement in current electricity.

V : 10 ELECTRIC CHARGES

As mentioned above, the phenomenon of electric charges was first noted over 2500 years ago. However, similar discoveries have been made by everyone early in life. What child has not been fascinated to discover that on a cold dry day the comb which has just straightened his hair will now pick up bits of paper? Who has not been startled by a shock after scuffing across a carpet to touch another person or a metallic object? Materials which have gained the property of attracting small bits of paper and other light objects are said to have an electric charge (Chap. 31, Exp. 12). Substances that do not have this charge are said to be neutral. Since many non-magnetic materials are attracted, it is evident that electric charges differ from magnetism. It has been found by many experiments that whenever two different substances are rubbed together each will become electrically charged. It is this charge that builds up in gasoline tank trucks as they move along the highways. To prevent sparking, which could cause an explosion, a chain drags behind the truck to allow the charge to leak off gradually. Responsibility for many fires has been traced to charges of static electricity and precautions are necessary in many industrial plants to ensure that sparking does not occur.

V : 11 KINDS OF ELECTRIC CHARGES

It is a simple matter to prove that a hard rubber or ebonite rod rubbed with cat's fur or flannel, or a glass rod rubbed with silk, will become electrically

charged (Sec. V:10). If we charge an ebonite rod in this way, suspend it by a stirrup from an insulated stand, and approach it with another charged ebonite rod (Fig. 23:1), the suspended rod is repelled. If the suspended ebonite rod is approached by a charged glass rod, attraction will be observed (Chap. 31, Exp. 13). Thus we can see that these are two different kinds of electric charges. In 1750 Benjamin Franklin introduced the term **negative** to describe the charge produced on an ebonite rod rubbed with fur or wool, and **positive** for the charge on a glass rod rubbed with silk. A simple law of electrical charges may now be stated: **like charges repel each other; unlike charges attract each other.**

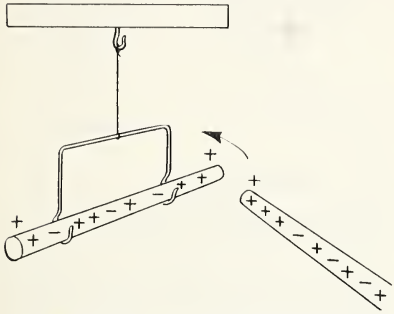
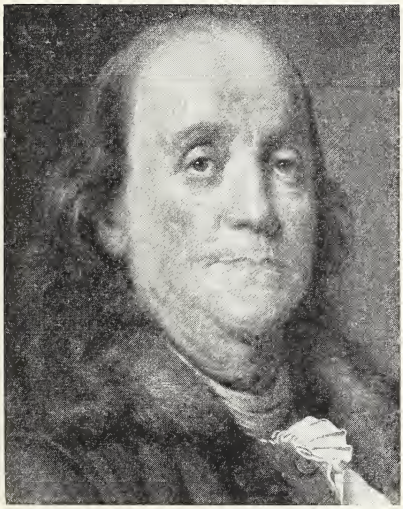


Fig. 23:1 Like Charges Repel.



University of Toronto

Benjamin Franklin

V : 12 THE ELECTRON THEORY

Our knowledge of the structure of matter has made great progress since the turn of the century. Experimental work beyond the scope of this text has led to a concept of the atom far different from that held until 1897. Until that time the atom was thought to be the smallest particle of matter. Since then our concept of the structure of the atom has been constantly changing. For our purposes it is convenient to think of the atom as follows:

1. It may be pictured as a miniature solar system with a central relatively large mass, called the **nucleus** corresponding to our sun, and a number of smaller objects, called **electrons** travelling in their orbits about the nucleus much as the planets move around the sun.
2. The nucleus is composed of two kinds of particles:
   (a) **Protons**—which are positively charged and are considered to have unit mass.
   (b) **Neutrons**—which have no electric charge and have the same mass as the proton.
3. The electrons are negatively charged and are approximately $\frac{1}{1840}$ as heavy as a proton.
4. Atoms are normally neutral in charge. Therefore we may conclude that in each atom there must be as many electrons moving around the nucleus as there are protons within the nucleus.

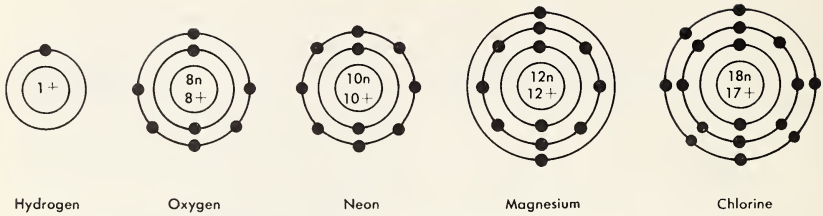


Fig. 23:2 Diagrams of Several Atoms—Electrons (●), Protons (+), Neutrons (n).

5. There are over one hundred different kinds of atoms known at the present time. Scientists believe that even more will be identified in the near future. The atoms of different elements differ from each other in the numbers of protons and neutrons contained in the nucleus and in the number and arrangements of electrons in their orbits. Some typical diagrams of atoms are shown in Fig. 23:2.

An understanding of this theory of atomic structure enables us to explain why an object becomes charged by friction. Tremendous forces are required to separate a proton from the nucleus of an atom. However, it is relatively easy to cause an electron to leave an atom or to move to another atom. When an ebonite rod is rubbed with cat's fur, electrons are transferred from the fur to the ebonite and the rod becomes negatively charged. The fur, having lost electrons, becomes positively charged. Similarly, when a glass rod is rubbed with silk, electrons are transferred from the glass to the silk so that the glass becomes positive and the silk negative.

We may now define a **positive charge** as a deficiency of electrons. A **negative charge** is a surplus of electrons. A **neutral body** has equal numbers of protons and electrons.

V : 13 ELECTROSCOPES

Before proceeding further in our discussion of electrostatics it is convenient to study the means by which electric charges may be detected and identified. Instruments used for this purpose are called electroscopes.

(a) The Pith Ball Electroscope

The simplest form of electroscope consists of two balls of dried elder pith, each about the size of a pea, suspended side by side from an insulated stand by silk threads (Fig. 23:3). When the pith

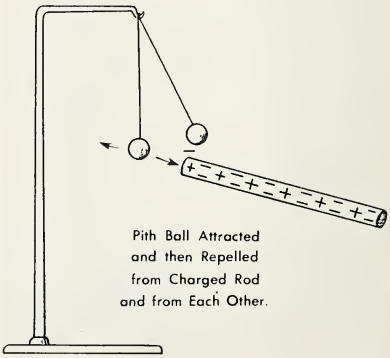


Fig. 23:3 A Pith Ball Electroscope.

balls are approached by an uncharged object no attraction or repulsion will be noted. When a charged ebonite rod is touched to the pith balls, they will be

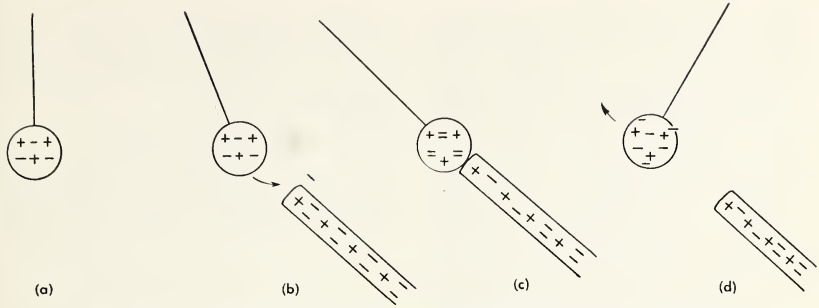


Fig. 23:4 Charging a Pith Ball Electroscope Negatively by Contact.

seen to be attracted, cling to the rod for a moment, and then be violently repelled from it. The pith balls have become negatively charged and they will spring apart due to the repulsion of like charges. The stronger the charge, the greater is the repulsion. When the charged pith balls are now approached by an object bearing the same kind of charge, they will be repelled from it. If the charge on the object is opposite to that placed on the pith balls, they will be attracted to it (Chap. 31, Exp. 14).

These observations may be explained readily by reference to the electron theory. The rod, being negatively charged, has an excess of electrons. Because the rod is charged and the pith balls are not, they are attracted to it. As the pith balls touch the rod some electrons move from the rod to the electroscope. Thus the pith balls become negatively charged and are repelled. This series of events is shown diagrammatically in Fig. 23:4. It is frequently convenient to use an electroscope with only one pith ball as shown for electrostatic experiments.

Similarly, the pith ball may be given a positive charge by touching it with a charged glass rod. In this case the electrons will be transferred from the pith ball to the rod which, being positively charged, has a deficiency of electrons. Thus, the pith ball, when charged by contact, receives the same charge as the charging object.

(b) The Gold-Leaf Electroscope

This instrument, shown in Fig. 23:5 is much more sensitive than that described above. It consists of a piece of

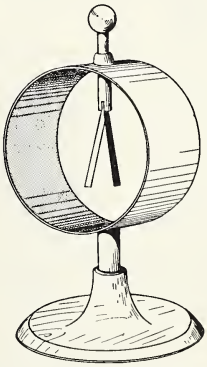


Fig. 23:5 Gold-Leaf Electroscope.

gold-leaf or thin aluminum-foil attached at its upper edge to a brass plate at the end of a brass rod. This assembly is enclosed in a metal case with glass windows for observation. The rod is in-

sulated from the case by a ring of sulphur, wax, or rubber. The rod generally terminates at the upper end in a knob or flat disc to receive the charge.

A negative charge on the electroscope may be obtained by touching the knob with a negatively charged rod (Chap. 31, Exp. 15). Electrons will be transferred from the charged rod to the knob, rod, plate and leaf of the electroscope. The similar charge on the plate and leaf causes repulsion and the leaf diverges. The extent of this divergence is an indication of the strength of the charge. If the knob is now approached by an object bearing the same kind of charge as that on the electroscope, there will be further divergence of the gold-leaf. If, however, the object bears the opposite charge, the leaf will be seen to fall. When touched by a positively charged object, electrons will leave the electroscope and it will be left with a positive charge.

V : 14 CONDUCTORS AND INSULATORS

In some materials, mostly metals, the orbital electrons are so loosely bound that they will leave the atom readily. In some other substances the electrons are so tightly bound to their nuclei that their movement is slight. Materials in which electrons can move readily are called **conductors** (Chap. 31, Exp. 16). Conductors may be solids, liquids, or gases, although liquids and gases conduct electricity in a slightly different manner (Sec. V:40, V:77). Substances in which the electrons can not move readily are called **insulators**. A few common conductors and insulators are tabulated below.

V : 15 INDUCED CHARGES

Two metal spheres, *A* and *B* (Fig. 23:6), supported on insulated stands are placed in contact so that they form a

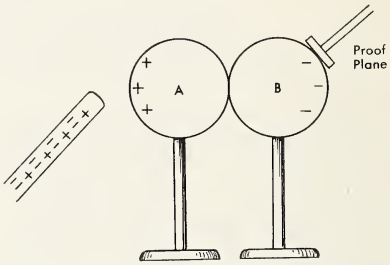


Fig. 23:6 Electrostatic Induction.

single conductor. If a negatively charged ebonite rod is now brought near to *A* as described in chapter 31, experiment 17, and the surfaces of the spheres are examined for charge by means of a charged electroscope and a proof plane (a small metal disc at the end of an insulating-handle used to transfer charges to an electroscope), it will be found that the surface of *A* near the ebonite rod has acquired a positive charge. A negative charge will be found on the surface of *B* remote from the rod. If the ebonite rod is removed and the spheres

GOOD CONDUCTORS	POOR CONDUCTORS	GOOD INSULATORS
metals	dry wood	hard rubber
graphite	paper	paraffin wax
water solutions of acids, bases, and salts	alcohol	sulphur
	kerosene	mica
	pure water	porcelain
		dry air

again examined, no charges will be found. This is an example of **electrostatic induction.** The charges discovered on the spheres while the charged rod was near are known as **induced charges.** They are due to the repulsion of electrons from sphere *A*, which thus becomes positively charged, to sphere *B*, which thus acquired a negative charge. Induced charges are possible only with conductors since there are no free electrons in insulators to allow the movement necessary. If *A* and *B* are separated while the ebonite rod is still in position, permanent charges will remain on the spheres (positive on *A*, negative on *B*). If the rod is now removed and the spheres allowed to touch, it will be found that no charge remains on either sphere. We may conclude then, that **induced charges are equal.**

V : 16 CHARGING BY INDUCTION

Approach, but do not touch, the knob of a gold-leaf electroscope with a negatively charged ebonite rod (Chap. 31, Exp. 18). The leaf diverges as shown in Fig. 23:7 because electrons are repelled to the plate and leaf. Keeping the charged rod near, touch the knob with a finger, that is, "ground" it. The leaf will fall as electrons are repelled from it to "ground". Next, remove your finger, and then the charged rod. The leaf will diverge again. The remaining electrons are distributed over the electroscope which is left with a deficiency of electrons and thus a positive charge.

In order to give the electroscope a negative charge the above procedure must be followed using a positively charged rod. This method is illustrated in Fig. 23:8. Students are advised to draw the diagrams and make the necessary explanations bearing in mind that "ground" acts as a source of extra electrons.

V : 17 THE ELECTROPHORUS

About 1775 Volta invented the simplest form of machine to produce electric charges by induction, called the electro-

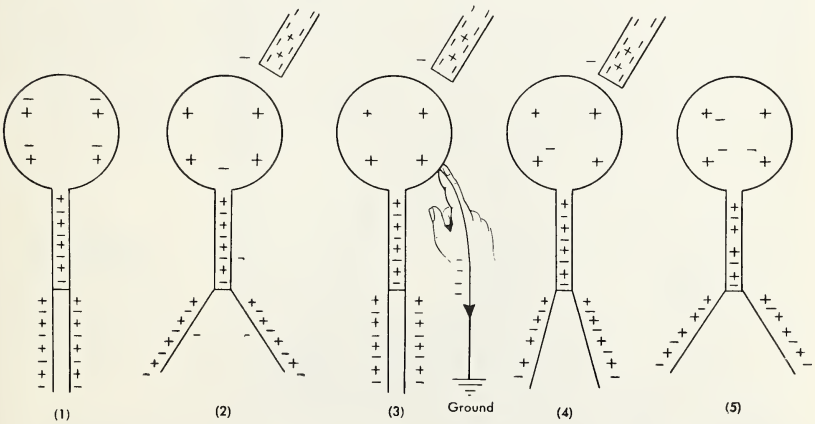


Fig. 23:7 Charging Gold-Leaf Electroscope Positively by Induction.
(1) Uncharged electroscope.
(2) Approach with charged ebonite rod (—).
(3) Touch with finger (ground)
(4) Remove finger
(5) Remove charged rod.

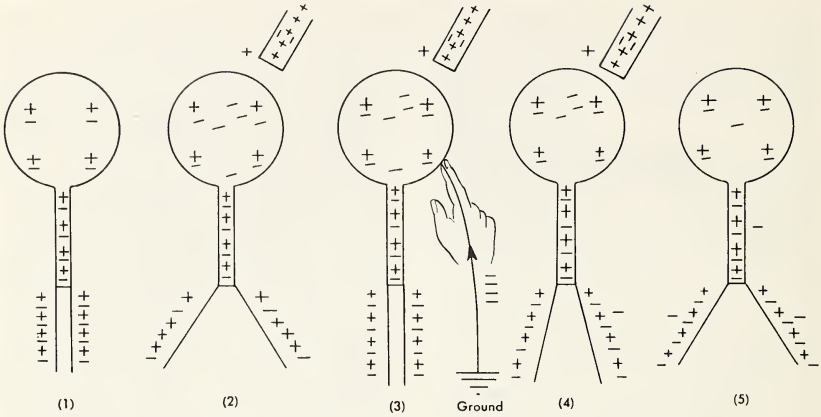


Fig. 23:8 Charging Gold-Leaf Electroscope Negatively by Induction.

(1) Uncharged electroscope
(2) Approach with charged glass rod (+)
(3) Touch with finger (ground)
(4) Remove finger
(5) Remove charged rod

phorus. It consists of a hard rubber or ebonite cake and a separate metal disc provided with an insulating handle. The ebonite cake is charged negatively by rubbing with fur. The metal disc is then placed on it and touched with a finger. If the disc is then removed by means of the insulating handle it will be found to possess a relatively strong positive charge. The disc has been charged by induction.

In order to explain this we must realize that neither the disc nor the cake are perfectly smooth. Thus actual contact between them is made at very few points and we may assume that the two are separated by a thin air space over most of their areas. By induction a positive charge will appear on the under surface of the disc and a negative charge on its upper surface. When the

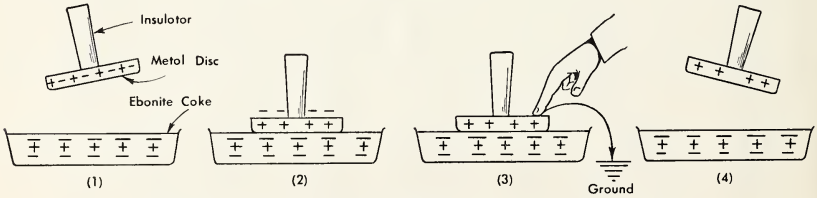


Fig. 23:9 Charging an Electrophorus by Induction.

(1) Ebonite rubbed and given negative charge.
(2) Electrons repelled to top surface of metal disc.
(3) Electrons repelled through finger to ground.
(4) Metal disc positively charged. Ebonite cake still negatively charged.

finger touches the upper surface, electrons are repelled from the disc to "ground" and on removal of the finger the disc is left with a deficiency of electrons and a positive charge. These changes are illustrated in Fig. 23:9. It will be noted that very little of the charge is removed from the ebonite cake. The disc, therefore, can be charged repeatedly in the manner described above without recharging the ebonite.

V : 18 THE WIMSHURST MACHINE

This is a well-known laboratory machine for the continuous production of electric charge by inductive separation and was first made by James Wimshurst about 1878. It consists of two circular ebonite or shellacked glass plates mounted close together and geared so as to rotate in opposite directions (Fig. 23:10). On the outer surface of each plate near the rim are fixed an even number of equally spaced thin metal sectors which serve both as inductors and carriers. Wire brushes, supported at the ends of two metal rods placed at right angles to one another across each plate, rub against the sectors as they pass towards collecting combs consisting of a number of sharp metal teeth directed towards the sectors on both front and back plates. These combs are placed at either end of the horizontal diameter of the plates and each is connected to a discharging knob supported above the machine.

The action of this machine is beyond the scope of this text. Interested students are advised to refer to a good encyclopedia. It is interesting to note that with a 1 cm. air gap, 30,000 volts are required to cause a spark discharge between the terminals. In spite of the high voltage there is little danger from the discharge because of the small quantity of electricity involved.

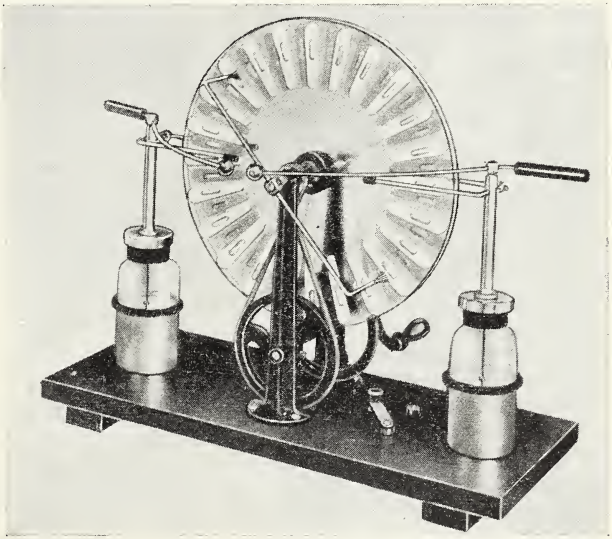


Fig. 23:10
Wimshurst Machine.

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V : 19 DISTRIBUTION OF CHARGES

The location of charges on a charged body may be demonstrated as in chapter 31, experiment 19A, using Biot's Spheres shown in Fig. 23:11. The apparatus consists of an insulated metal sphere over which two tightly-fitting

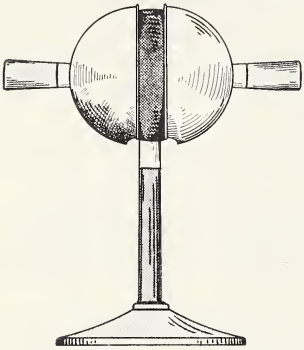


Fig. 23:11 Biot's Spheres.

insulated metal hemispheres can be placed to cover it completely. A charge is given to the sphere and then the hemispheres are fitted tightly over it. When the hemispheres are removed and tested using a proof plane and electroscope, each will be found to possess a charge, while the sphere is found to have lost its charge. The charge, then, must have passed to the hemispheres as they formed the outer surface of the sphere. **Charges reside only on the outer surface of a charged conductor.**

To determine how the charge is distributed over the surface of a charged conductor we can charge several insulated conductors of different shapes as described in chapter 31, experiment 19B. On investigation with a proof plane and electroscope the following observations are made:

1. In conductor (a) the leaves of the electroscope show the same divergence no matter what part is touched by the proof plane.
2. In conductor (b) the divergence proves to be a little greater from tests at the ends than at the centre.
3. In conductor (c) the divergence is much greater from tests at the more pointed parts of the conductor than elsewhere.

From these tests we may conclude that **the charge on a conductor tends to be concentrated at the more pointed parts of the surface.**

V : 20 LIGHTNING-RODS

About the middle of the eighteenth century Benjamin Franklin demonstrated in his classic kite experiment that thunder-clouds carry electrical charges and that lightning is an electrical discharge or spark between clouds, or clouds and objects on the earth.

If a metallic point is connected to one of the discharge knobs of a Wimshurst machine, as shown in Fig. 23:12, the streaming of charge away from the point is sufficient to blow aside the

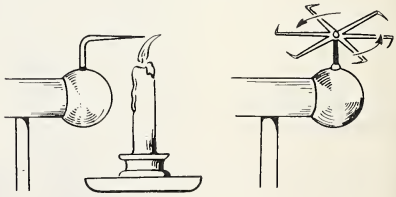


Fig. 23:12 Action of Points

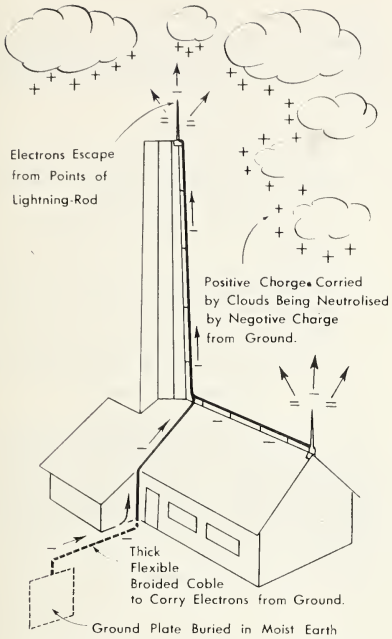


Fig. 23:13 Use of Lightning-Rods.

flame of a small candle (Chap. 31, Exp. 20). The **action of points** is as if the point produces a self-discharging action, the charge on the conductor streaming away from it as an "electric wind".

Franklin made use of this action of points as he designed the lightning-rod to protect buildings against the dangers of lightning. As a charged cloud passes over the earth it induces the opposite charge on objects below. If the charge becomes great enough a flash of lightning occurs with its accompanying thunder, a shock-wave, caused by the sudden and violent expansion of the air heated by the discharge. The rods are so designed that the induced charge escapes from the sharp points and so an accumulation of charge is prevented. If the lightning does strike the rods, a good conductor leads the electricity safely to ground through a metal rod deeply buried in the damp ground near the building (Fig. 23:13).

V : 21 QUESTIONS

1. (a) What is the meaning of static electricity?
   (b) How is it produced?
   (c) How is it detected?
2. (a) Name two kinds of static electricity. How is each produced?
   (b) How would you prove that there are two kinds?
   (c) State the law for electrical charges.
3. (a) Describe in point form our modern concept of the structure of an atom.
   (b) In terms of the electron theory, what is (i) a positively charged, (ii) a negatively charged, (iii) a neutral body?
   (c) Why does (i) ebonite become negative when rubbed with wool, (ii) glass become positive when rubbed with silk? What is the electrical condition of the wool and silk afterward?
4. (a) What are the purposes of electroscopes?
   (b) Describe and explain what occurs when (i) a positively charged, (ii) a negatively charged object is brought up to an uncharged pith ball electroscope.
   (c) How would you use it to identify an unknown charge?
5. (a) Describe the structure of the gold-leaf electroscope and state the purpose of each part.

(b) Explain how to charge it (i) positively, (ii) negatively by contact.
(c) How would you use it to identify an unknown charge?

6. (a) What is a good conductor of electrical charges? Give examples.
(b) What is an insulator of electricity? Give examples.
(c) How could you use a gold-leaf electroscope to show that iron is a better conductor than wax?

7. (a) What is meant by electrostatic induction?
(b) You have a charged glass rod and two metal spheres mounted on insulated stands. Describe how you would charge one sphere negatively, and the other positively, by electrostatic induction.
(c) How would you verify that the spheres were oppositely charged?

8. Describe, using a series of diagrams to illustrate your answer, how to charge a gold-leaf electroscope (a) positively, (b) negatively by induction.

9. Explain the following:
(a) the metal disc of an electrophorus can be repeatedly charged without recharging the ebonite cake.
(b) the purpose of the Wimshurst machine.
(c) electrical charges reside on the outside of a conductor.
(d) lightning-rods are sharply pointed.
(e) lightning-rods are connected by a good conductor to ground.

10. A positively charged cloud hovers over a tall church spire. What will be the resulting electrical condition of the spire? What will happen if a large enough charge accumulates on the cloud?

CHAPTER 24 ELECTRIC CURRENT

V : 22 INTRODUCTION

In chapter 23 it was shown that electrons moved between the terminals of the Wimshurst machine and that lightning is actually a movement of electrons between earth and charged clouds. Such movement of electrons is called an electric current.

In the eighteenth century Luigi Galvani, an Italian physiologist, discovered that a freshly dissected frog's leg showed violent muscular contractions when touched by two dissimilar metals. He erroneously attributed this property to the frog, and it remained for Alessandro Volta, an Italian professor of physics, to demonstrate a short time later that the frog's leg had acted only as a sensitive detector of electricity which had been produced by contact with the dissimilar metals. Volta showed that this electricity was identical with that produced by frictional means (Sec. V:10). From this beginning he constructed the first source of continuous electric current, the voltaic cell (Sec. V:23).

From the time of publication of Volta's works in 1800, there has been continuous progress in the field of electricity. The sections that follow will help to give you an understanding of the fundamentals of electricity that mean so much in our modern way of life.

V : 23 THE VOLTAIC CELL

Every high-school student is familiar with the tiny dry cell that is used to operate a flashlight and the larger storage battery used to start a car; these are just two modern forms of the **voltaic cell**. A voltaic cell consists of two dissimilar materials immersed in a solution of an acid, base, or salt, called the electrolyte.

The simplest form of voltaic cell consists of a copper plate and a zinc plate placed in a vessel containing dilute sulphuric acid (Chap. 31, Exp. 21). As a result of the chemical action in the cell the copper plate becomes positively charged and the zinc plate negatively charged. If the plates are

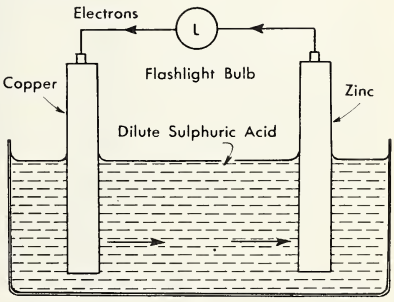


Fig. 24:1 Diagram of Simple Voltaic Cell.

then connected by a conductor (Fig. 24:1) the potential difference between them will cause electrons to flow from the zinc to the copper. The circuit is completed through the electrolyte. As the current flows, hydrogen is deposited on the copper plate and zinc sulphate dissolves in the electrolyte as the zinc is gradually used up. The potential difference between the plates is approximately 1.1 volts. This P.D. is independent of the size of the plates used, but varies with the materials used. In all such cells chemical energy is transformed into electrical energy.

V : 24 DEFECTS OF THE VOLTAIC CELL

1. Polarization

If a small flashlight bulb is connected in the circuit of a voltaic cell it will glow brightly for a short time and then fade gradually until no light is seen (Chap 31, Exp. 21). It is apparent that the current delivered by the cell has decreased. This effect is caused by **polarization**, which is the accumulation of bubbles of hydrogen on the positive plate. The hydrogen deters the acid from reaching the plate and serves as an insulator preventing further transfer of electrons. To restore a polarized cell the bubbles may be removed mechanically by wiping the positive plate, shaking it, or, chemically, by adding an oxidizing agent such as potassium dichromate to the solution. Such a chemical releases oxygen which unites with the hydrogen to form water. Substances added for this purpose are called depolarizing agents.

2. Local Action

If impure or commercial zinc is used in the cell, the plates are found to deteriorate rapidly even when the cell is not in use. This is caused by small particles of such impurities as lead, iron, carbon, etc., occurring in the plates used. Many small voltaic cells are set up between these impurities and the zinc, and local action continues until the plate

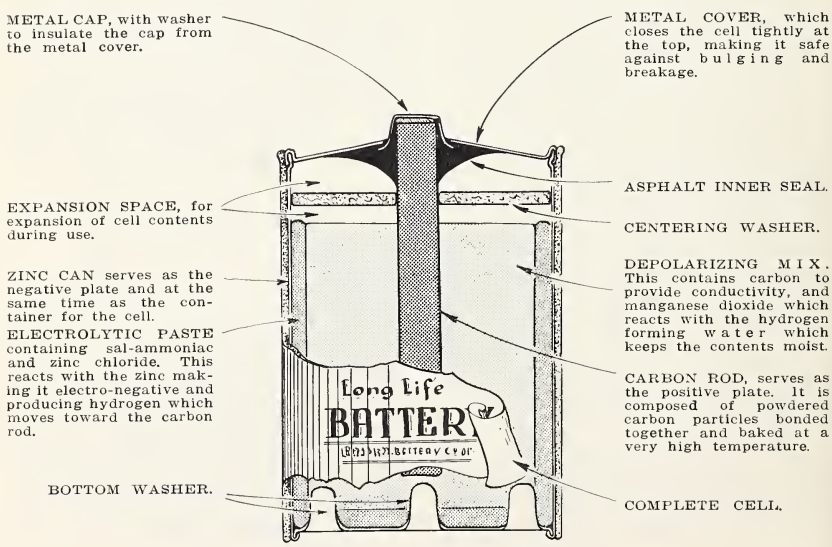


Fig. 24:2 Structure of a Dry Cell.

is consumed. Thus zinc is used up while delivering no useful current outside the cell.

The use of pure zinc, of course, would be a simple remedy, but pure zinc is expensive. A more practical method of eliminating local action is to amalgamate the surface of the zinc plate with mercury. The zinc dissolves in the mercury and gradually comes to the surface where it reacts with the acid. The impurities are covered by the mercury and their contact with the electrolyte is prevented.

V : 25 THE DRY CELL

Obviously, the voltaic cell described in section V:23 has several disadvantages in practical use. The dry cell eliminates many of these undesirable features. Its structure is shown in Fig. 24:2.

As the cell is used the zinc becomes thinner and may eventually break open allowing the paste to dry out. This increases the internal resistance of the cell to such an extent that little, if any, current will flow in the circuit.

The potential difference of a fresh dry cell is approximately 1.5 volts regardless of size. Large dry cells are able to produce current over longer periods than smaller cells. Dry cells of various sizes and shapes have been made to fill many needs. They are widely used for flashlights, portable radios, telephones, hearing aids, lanterns, and many other devices used by the armed forces and industry.

V : 26 THE ELECTRIC CIRCUIT

The flow of electrons in a wire is so similar to the flow of water in a pipe that a comparison may be made as follows:

The Water System	The Electric Circuit
1. Water current is the flow of water through the system.	1. Electric **current** is the flow of electrons through the wires.
2. Water flows through a closed system of pipes between source and user.	2. Electrons flow through a closed path of wires called a **circuit.**
3. The quantity of water in a system is measured in gallons or similar units.	3. The **quantity** of electricity is measured in **coulombs.** A coulomb is equal to approximately 6.28 billion billion electrons.
4. The current of water is measured in gallons moving through the pipe in a unit of time.	4. The **electric current** is measured in **amperes.** An ampere is the current when one coulomb passes a point in the circuit in 1 second.
5. Water current is reduced by the friction between the water and the pipes.	5. Electric current is decreased by the **resistance** of the conductor. The unit of resistance is the **ohm.**

THE WATER SYSTEM	THE ELECTRIC CIRCUIT
6. Water is driven through the pipes by pressure which is measured in pounds per square inch or related units. Pressure is provided by increasing the potential energy of the water by pumping it into high tanks. The force so created pushes the water to its destination although the water pressure decreases as the length of pipe increases.	6. Electrons move through a circuit because of a difference in electrical pressures or **potential difference** (P.D.) between points in the wire. This potential difference is measured in volts. The pressure difference is maintained by the use of batteries or cells which provide a source of electrons by means of the transformation of chemical energy. This potential difference is the **electromotive force** necessary to move the electrons through the wire. Resistance in the circuit causes a lowering of potential difference between points in the conductor. This is referred to as a **voltage drop.**

The units of electricity in common use and their symbols are summarized below for convenient reference:

(a) Quantity of electricity (Q) — unit is the **coulomb**
(b) Current of electricity (I) — unit is the **ampere**
(c) Potential difference (V) — unit is the **volt**
(d) Resistance (R) — unit is the **ohm**

Smaller or larger units are obtained by using submultiples or multiples of these as:

1 milliampere = 1/1000 ampere
1 microampere = 1/1,000,000 ampere
1 millivolt = 1/1000 volt
1 microvolt = 1/1,000,000 volt
1 microhm = 1/1,000,000 ohm
1 kilovolt = 1,000 volts
1 megohm = 1,000,000 ohms
etc.

V : 27 ELECTRIC CURRENT AND ELECTRON FLOW

Electric current has been defined as the flow of electrons through the wires of a circuit (Sec. V:26). From the beginning of electrical theory, the current has been considered to flow, as is the case with water, from the place of high potential to the place of lower potential. Early scientists considered the positive side of a source of electricity to be at a higher potential than the negative side. Thus, the convention that electric current flows from positive to negative came into common use.

We now know that the negative side of a source has a surplus of electrons and the positive side a deficiency of electrons (Sec. V:12). Following a fundamental law of nature, electrons move from where there are more to where there are fewer. Electrons, there-

fore, actually move from negative to positive.

In all work on electronics, including radio, it is necessary to refer to electron movement in order to understand the operation of modern devices. However, in most other electrical work, unless definitely specified, references have been confined in the past to the conventional current flow, i.e., positive to negative. In most modern writings, including this text, all references are to the electron flow. No difficulty need arise if the difference between current flow and electron flow is recognized.

V : 28 TYPES OF CIRCUITS

Two main types of connection are in common use in electric circuits and all others are merely combinations of these.

(a) Series Circuit

In this arrangement the current goes from one terminal of the source to one terminal of the first appliance. On passing through this, it flows to the next and the next until it reaches the other terminal of the source (Fig. 24:3). All

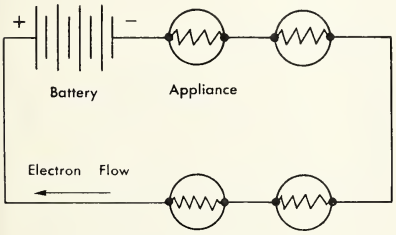


Fig. 24:3 Series Circuit.

the current must pass through each appliance, causing a voltage drop (Sec. V:26) in the circuit. A break in any part of the circuit will stop all flow of current. Series circuits are frequently found in Christmas-tree lights, but are seldom used for other purposes.

(b) Parallel Circuit

In the parallel or shunt type of connection the conductor from the positive terminal of the source is connected to one terminal of each appliance and the negative terminal of the source is connected to the other terminal of each

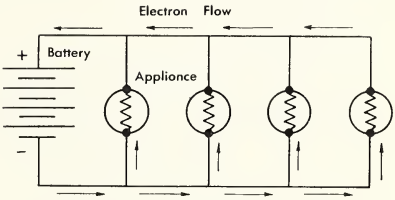


Fig. 24:4 Parallel Circuit.

appliance (Fig. 24:4). This is typical of wiring circuits used in your home. Each appliance receives current independently from the others and thus a break in one does not interfere with the operation of the rest.

V : 29 ARRANGEMENT OF CELLS

(a) Series

If the resistance in a circuit is so great that the P.D. of one cell is not sufficient to provide the required current, a number of cells may be connected in series. The positive terminal of the first cell is connected to the negative of the second, the positive of the second

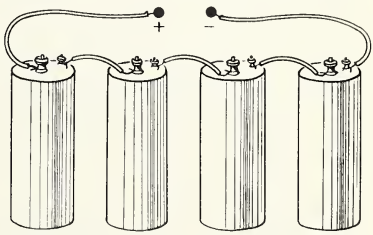


Fig. 24:5 Battery of Cells Connected in Series.

to the negative of the third, etc. Such an arrangment of two or more dry cells is called a **battery.** When cells are connected in series the total P.D. is equal to the sum of the voltages of the individual cells. A forty-five volt radio B-battery, for example, is composed of thirty dry cells connected in series (Fig. 24:5).

(b) Parallel

If the resistance in a circuit is low and a large current is to be used, dry cells are connected in parallel. All the positive and negative terminals are

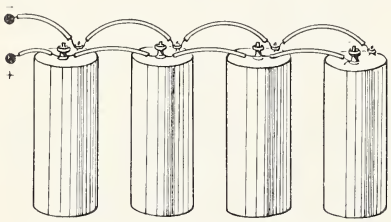


Fig. 24:6 Battery of Cells Connected in Parallel

connected as shown in Fig. 24:6. The P.D. of such a battery remains the same as that of a single cell. Since the current is provided equally by all cells the parallel arrangement gives a large current for a relatively long period of time.

V : 30 SWITCHES

Just as taps are inserted in a pipe line to stop the flow of water, so switches are used to interrupt the flow of electric current in a circuit. These are devices which break or complete the conducting path. Many types of switches are in common use, but only two will be described here.

(a) Knife Switch

Modifications of the common knife switch are used to control many household circuits. The main switch is generally of the type shown in Fig. 24:7a. Wall switches are smaller variations of the same type.

(b) Push Button Switch

This familiar type is shown in Fig. 24:7b. It is used to control low-voltage

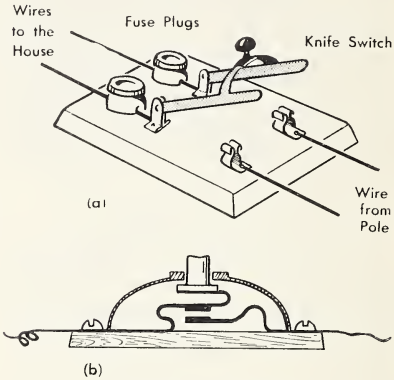


Fig. 24:7 Switches
(a) Main House Switch
(b) Push Button Switch

circuits in which the current is required for short intervals only. Electric doorbells, signal buzzers, etc. make use of this type of switch.

Many newer types of switches have been devised for specific purposes, but the scope of this text does not allow their description at this time. The interested student will find information on mercury switches, automatic circuit breakers, and special switching arrangements such as those used to control a stairway light from either upstairs or downstairs in any good wiring handbook.

V : 31 USE OF SYMBOLS

In order to represent the many pieces of equipment encountered in electrical drawings and circuit diagrams, a number of conventional symbols have been de-

vised. A few of the most common symbols are introduced at this point so that the student may use them in the work which follows.

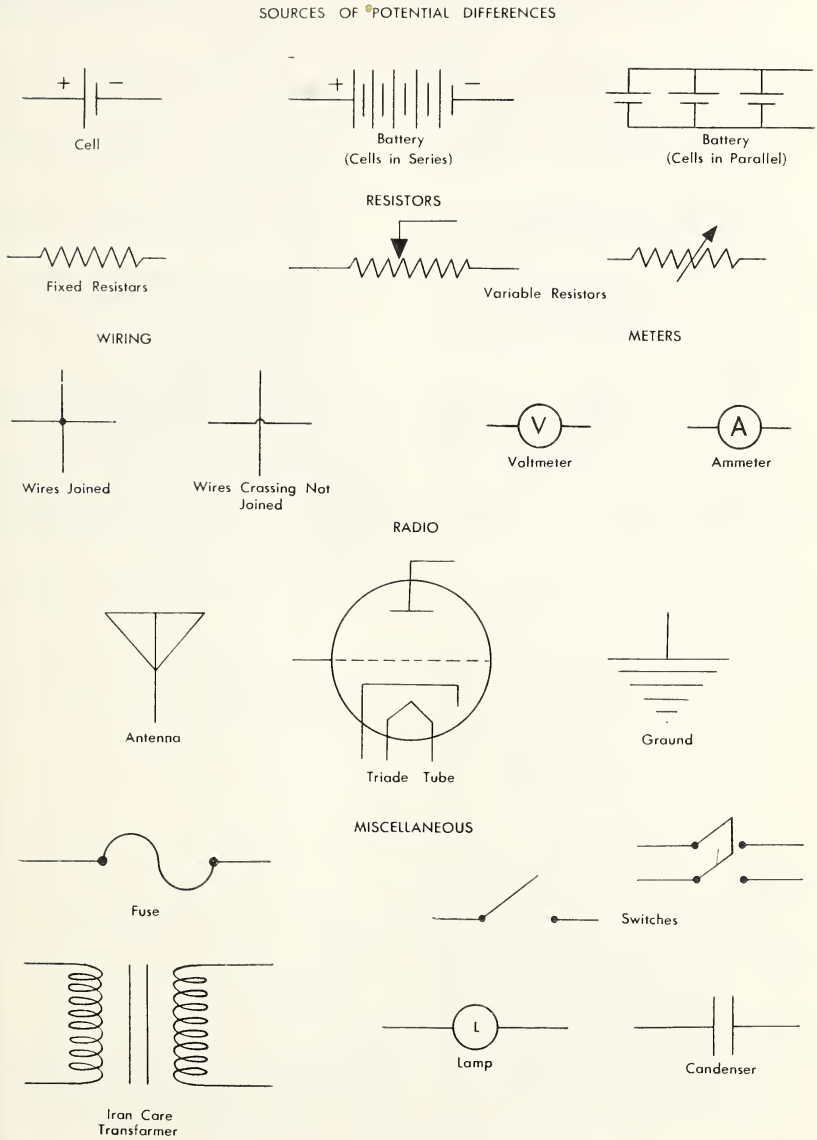


Fig. 24:8 Common Electrical Symbols

V : 32

QUESTIONS

1. (a) What is an electric current?
   (b) How is an electric current produced?

2. (a) Make a diagram of a simple voltaic cell. Mark the direction of the electric current (electron flow).
   (b) What determines the voltage of such a cell?
   (c) What transformation of energy takes place in a voltaic cell?

3. (a) What are the two principal defects in a voltaic cell?
   (b) How are the defects overcome?

4. (a) Make a labelled diagram of a dry cell.
   (b) State the purpose of each structure or material labelled in part (a).
   (c) What is the voltage of a dry cell?
   (d) Why are dry cells made in different sizes?

5. Define the following: electric circuit, ampere, coulomb, electrical resistance, potential difference.

6. (a) Name the two principal types of electrical circuits and define each.
   (b) State the advantages and disadvantages of connecting electric lights each way.
   (c) Make a diagram showing three lights connected in each of these ways.

7. (a) Distinguish between the arrangement of cells in series and in parallel.
   (b) What is the purpose of each of these arrangements?
   (c) What would be the potential difference of three dry cells connected (i) in series (ii) in parallel?

8. Make a diagram of a circuit containing a cell, a fixed resistor, two wires joined, two wires crossing but not joined, a fuse, a lamp, a switch.

CHAPTER 25 OHM'S LAW AND RESISTANCE

V : 33 OHM'S LAW

The relationship between current strength, potential difference, and resistance of the circuit is of the utmost importance in practical electricity (Chap. 31, Exp. 22). In such an experiment the potential difference across the resistance coil is varied by connecting different numbers of dry cells in the

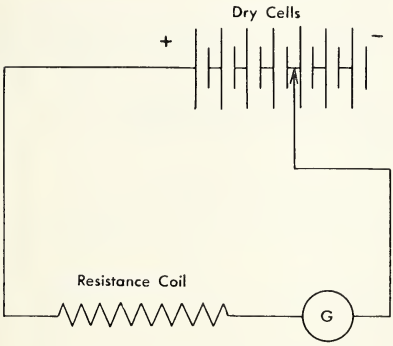


Fig. 25:1 Ohm's Law Circuit.

circuit. The strength of the current flowing through the coil is gauged by the deflection of a galvanometer needle (Sec. V:53). A circuit for this arrangement is shown in Fig. 25:1. Let us consider some sample results of such an experiment:

No. of Cells	Galvanometer deflection (divisions)	No. of Cells ÷ Deflection
1	4.9	0.204
2	9.8	0.204
3	14.8	0.203
4	19.7	0.203
5	24.5	0.205

∴ Within the limits of experimental error.

$$\frac{\text{Number of cells}}{\text{Galvanometer deflection}} = \text{a constant}$$

And, since the P.D. across the resistance coil varies directly as the number of cells used, and the galvanometer deflection is proportional to the current through the coil, we have

$$\frac{\text{Potential Difference}}{\text{Current Strength}} = \text{a constant}$$

or

Current Strength is proportional to Potential Difference

This relationship was first investigated early in the nineteenth century by George Simon Ohm. The results of his work, published in 1826, are embodied in the law bearing his name. **Ohm's Law** may be stated as follows:

The current through a given conductor is proportional to the potential difference between its ends.

It must, however, be emphasized that

this law is true only if the temperature remains constant (Sec. V:34).

The value of the constant derived above is known as its resistance (R).

The unit of resistance is the **ohm** which may be defined on the basis of Ohm's Law as being **the resistance of a conductor which permits a current of one ampere to flow when a potential difference of one volt is applied across it.**

Ohm's Law may be written, then, as

$$\frac{\text{Potential Difference}}{\text{Current}} = \text{Resistance}$$

or

$$\frac{\text{Volts}}{\text{Amperes}} = \text{Ohms}$$

or

$$\frac{V}{I} = R$$

This formula may be rearranged to read:

$$V = IR \text{ or } I = V/R$$

All of these forms will be found useful in numerical work.

Problem examples are given in section V:36.

V:34 FACTORS AFFECTING RESISTANCE

The resistance of a conductor depends on four main factors:

(a) **Length**—The resistance of a conductor varies directly as its length i.e., twice the length gives twice the resistance; half the length gives half the resistance; etc.

(b) **Cross-section**—The resistance of a conductor varies inversely as the area of its cross-section i.e., twice the cross-sectional area gives half the resistance; half the cross-sectional area gives twice the resistance; etc.

(c) **Temperature**—In most metals an increase in temperature causes an increase in resistance, but in some substances such as glass, carbon and electrolytes an increase in temperature causes a decrease in resistance.

(d) **Material**—Materials differ widely in their resistances. Good conductors such as copper and aluminum have very low resistances. Poor conductors such as nichrome and manganin have much higher resistances. Good insulators, such as glass, mica, etc., have very high resistances.

RELATIVE RESISTANCES OF SOME COMMON MATERIALS
(IN OHM-CMS AT 20°C.)

	$\times 10^{-6}$
Aluminum	2.83
Copper	1.72
Iron	10.0
Mercury	95.8
Nichrome	100
Platinum	10.0
Silver	1.63
Tungsten	5.51

V:35 RESISTORS IN SERIES AND IN PARALLEL

The potential difference which causes the current to flow between the ends of a resistor is frequently called the **voltage drop** across the resistor. The value of a voltage drop (V) may be readily calculated by using Ohm's Law.

(a) Resistors in Series

If resistances of r_1, r_2 and r_3 ohms are

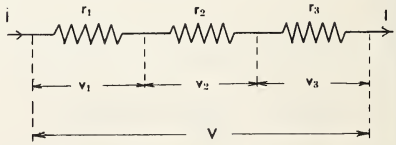


Fig. 25:2 Resistors in Series.

joined end to end as shown in Fig. 25:2, and a current of I amperes is passed

through them, the voltage drop across each ($\because V = IR$) will be respectively:

$$v_1 = Ir_1,\ v_2 = Ir_2,\ v_3 = Ir_3$$

The total voltage drop V will be

$$v_1 + v_2 + v_3 \text{ or } I\,(r_1 + r_2 + r_3).$$

But $V = IR$, where R is the total resistance in the circuit.

$$\therefore IR = I\,(r_1 + r_2 + r_3)$$
$$\text{and } R = r_1 + r_2 + r_3$$

(b) Resistors in Parallel

By connecting resistors in parallel, alternative paths are provided for the

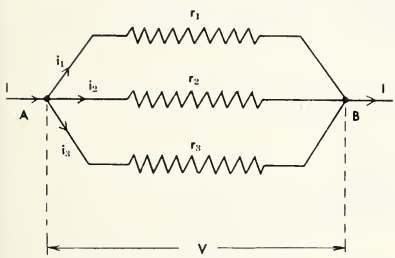


Fig. 25:3 Resistors in Parallel

current through the circuit (Fig. 25:3). The current, I, divides at A so that i_1 passes through r_1, i_2 through r_2, and i_3 through r_3. The potential difference between A and B is V volts and the total effective resistance in the circuit is R ohms.

$$\because I = \frac{V}{R},$$

$$\therefore i_1 = \frac{V}{r_1},\ i_2 = \frac{V}{r_2},\ i_3 = \frac{V}{r_3}$$

$$\text{But } I = i_1 + i_2 + i_3$$

$$\therefore \frac{V}{R} = \frac{V}{r_1} + \frac{V}{r_2} + \frac{V}{r_3}$$

$$\text{And } \frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}$$

Thus we see that when resistors are in series, the total resistance of the circuit equals the sum of the individual resistances. When resistors are in parallel, the reciprocal of the total resistance equals the sum of the reciprocals of the individual resistances.

Note The reciprocal of the resistance is known as the *conductance* of a conductor. The unit of conductance is the *mho*. Thus a wire with a resistance of 2 ohms will have a conductance of half a mho.

V : 36 PROBLEM EXAMPLES INVOLVING OHM'S LAW

Example 1

Calculate the resistance of a light bulb which carries a current of 2 amperes when connected to the 110 volt circuit.

$V = 110$ volts

$I = 2$ amp.

$R = ?$

$$\because R = \frac{V}{I} \text{ (Ohm's Law)}$$

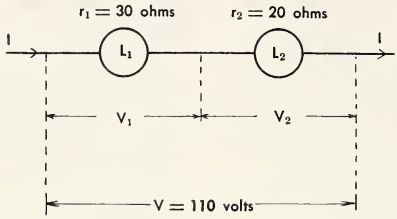
$$\therefore R = \frac{110}{2} = 55$$

$\therefore$ Resistance of the bulb $= 55$ ohms.

Example 2

If two lamps L_1, L_2, of resistance 30 ohms and 20 ohms are connected in series in a 110 volt circuit, determine (a) the total resistance in the

circuit (b) the current in the circuit (c) the voltage drop across each lamp.



(a)

$r_1 = 30$ ohms
$r_2 = 20$ ohms
$R = ?$

$\because R = r_1 + r_2$ (series connection)
$\therefore R = 30 + 20 = 50$
$\therefore$ total resistance in circuit $= 50$ ohms

(b)

$V = 110$ volts
$R = 50$ ohms
$I = ?$

$\because I = \dfrac{V}{R}$ (Ohm's Law)

$\therefore I = \dfrac{110}{50} = 2.2$

$\therefore$ current in the circuit $= 2.2$ amp.

(c)

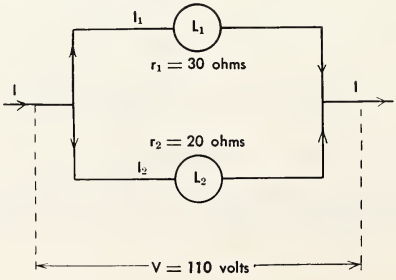
$I = 2.2$ amp.
$r_1 = 30$ ohms
$r_2 = 20$ ohms
$v_1 = ?$
$v_2 = ?$

$\because v_1 = Ir_1$ (Ohm's Law)
$\therefore v_1 = 2.2 \times 30 = 66$
$\therefore$ voltage drop across $L_1 = 66$ volts
$\because v_2 = Ir_2$
$\therefore v_2 = 2.2 \times 20 = 44$
$\therefore$ voltage drop across $L_2 = 44$ volts.

Example 3

If two lamps L_1, L_2, of resistance 30 ohms and 20 ohms are connected in parallel in a 110 volt circuit, determine

(a) the effective resistance of the circuit
(b) the current through each lamp.



(a)

$r_1 = 30$ ohms
$r_2 = 20$ ohms
$R = ?$

$\because \frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$ (parallel connection)

$\therefore \frac{1}{R} = \frac{1}{30} + \frac{1}{20} = \frac{5}{60} = \frac{1}{12}$

$\therefore R = 12$

$\therefore$ effective resistance of the circuit $= 12$ ohms.

(b)

$V = 110$ volts
$r_1 = 30$ ohms
$r_2 = 20$ ohms
$I_1 = ?$
$I_2 = ?$

$\because I_1 = \frac{V}{r_1}$ (Ohm's Law)

$\therefore I_1 = \frac{110}{30} = 3.7$

$\therefore$ current through $L_1 = 3.7$ amp.

$\because I_2 = \frac{V}{r_2}$

$\therefore I_2 = \frac{110}{20} = 5.5$

$\therefore$ current through $L_2 = 5.5$ amp.

V : 37 TYPES OF RESISTORS

Resistors are used primarily to control current and potential difference in electric circuits. They are constructed in many forms and sizes varying from those which have resistances of only a fraction of an ohm, as used in some measuring instruments, to those having resistances of many megohms as found in radio receivers. In general, however, resistors may be classified as either fixed or variable.

(a) Fixed Resistors

These may be constructed of short lengths of metal strip for very low resistances. Carbon or wire coils will provide higher resistances. Carbon resistors are frequently used in radios and other equipment in which some variation in resistance is permissible since such resistors may have an error tolerance of up to 20%. Wire-wound resistors may be made from special alloys, such as constantan or manganin (alloys of copper and nickel), having an accuracy within 1%. These are in general use for laboratory work and measuring-instruments.

A number of coils of fixed resistance are frequently arranged together in a resistance box. Details of construction are shown in Fig. 25:4. The ends of the

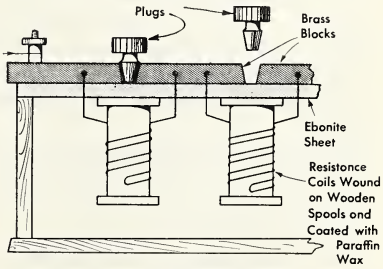


Fig. 25:4 Section of Resistance Box.

coils are attached to brass blocks on the top of the box and the current passes through the blocks when the shorting-plugs are placed in position. Pulling *out* the plug puts the resistor below it *into* the circuit. Such a box provides a large range of standardized resistors for laboratory use. To avoid errors in using a resistance box, the plugs must be inserted firmly. Plugs and sockets must be kept clean at all times.

(b) Variable Resistors (Rheostats)

Such resistors are usually continuously variable between certain limits. A common form of rheostat is shown in Fig. 25:5. It consists of a number of turns

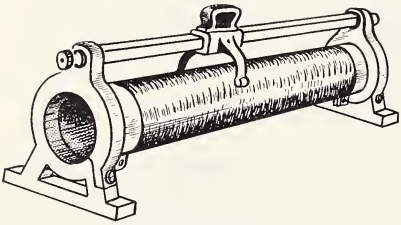


Fig. 25:5 Rheostat.

of wire wound on a porcelain tube. Above the coil is supported a metal bar along which moves a metal spring which can make contact at any turn of the coil. Connections are made to the end of the bar and to the end of the coil to enable the resistance in the circuit to be readily adjustable by moving the spring. Variable resistors such as this are of various sizes and shapes and are used in radio volume controls, for dimmer lights in theatres, starter boxes for heavy electric motors, etc.

V:38 METHODS OF MEASURING RESISTANCE

Although there are several methods of measuring resistance, the scope of this text permits the discussion of only the two (Chap. 31, Exp. 23 and 24) which follow:

(a) Voltmeter—Ammeter Method

The unknown resistance, R, is connected in the circuit shown in Fig. 25:6. The rheostat is adjusted until the ammeter (Sec. V:54) records any suitable

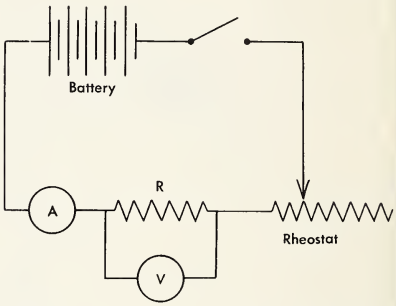


Fig. 25:6 Voltmeter-Ammeter Method for Determining the Value of an Unknown Resistance.

value for the current passing through the resistor. The voltmeter (Sec. V:54) across the resistor indicates the potential difference between the ends of the resistor. From this information the resistance may be calculated by using Ohm's Law.

Example

$I = 3$ amp.
$V = 12$ volts
$R = \ ?$

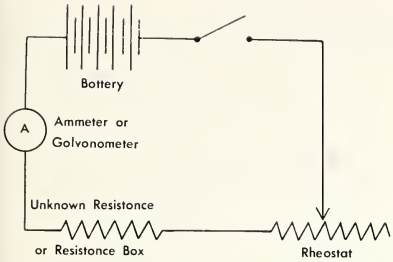
$$\because R = \frac{V}{I} \text{ (Ohm's Law)}$$

$$\therefore R = \frac{12}{3} = 4$$

$\therefore$ The resistance is 4 ohms.

(b) Substitution Method

The unknown resistance may be connected in a circuit as shown in Fig. 25:7. The rheostat is then adjusted until a large deflection is shown on the ammeter, or galvanometer (Sec. V:53). The meter reading is noted and the un-



known resistance is replaced by a resistance box. Plugs are removed until the meter reading is the same as before. The resistance of the box is now equal to the unknown resistance.

Fig. 25:7 Substitution Method for Determining the Value of an Unknown Resistance.

V : 39 QUESTIONS

A

1. (a) State Ohm's Law and explain how it may be determined.
   (b) Calculate the resistance of a light bulb which carries a current of 5.0 amperes when connected in a 110 volt circuit.
2. (a) In terms of Ohm's Law define: ohm, volt, ampere.
   (b) What weakness in these definitions is apparent?
3. (a) Explain electrical resistance.
   (b) List four factors affecting resistance. State the effect of each.
4. (a) What is meant by voltage drop across a resistor?
   (b) What is the effect on the total resistance of connecting a number of resistors (i) in series, (ii) in parallel?
   (c) If two lamps of resistance 50 ohms and 40 ohms are connected in series in a 110 volt circuit calculate (i) the total resistance of the lamps (ii) the current in the circuit (iii) the voltage drop across each lamp.
   (d) If two lamps of resistance 20 ohms and 40 ohms are connected in parallel in a 110 volt circuit, determine
   (i) the effective resistance of the circuit.
   (ii) the current through each lamp.
5. (a) Describe a resistance box and a rheostat. State the purposes of each.
   (b) What is the effect of removing a plug from a resistance box?
6. (a) Describe two methods for finding the resistance of a conductor.
   (b) In an electrical circuit, the ammeter reading is 5.5 amperes and the potential difference is 77 volts. What is the resistance?

B

1. What is the resistance of a flashlight bulb which carries a current of 0.50 ampere when connected in series with a 6.0 volt battery?
2. The resistance of a conductor is 25 ohms and it carries a current of 8.5 amperes. What is the potential difference?
3. How much current does a 36 ohm resistance draw when operated on a 120 volt line?
4. (a) What current flows through a 99.5 ohm resistance connected in series with a 12 volt battery having an internal resistance of 0.50 ohm?
   (b) What is the voltage drop across the resistance and across the battery?
5. (a) What is the resistance of an electric toaster which passes a current of 5.0 amperes when connected in a 110 volt circuit?
   (b) What resistance must be placed

in series with the toaster to lower the current to 4.0 amperes?

6. Eight lamps, each having a resistance of 330 ohms, are connected in parallel in the 110 volt circuit. Calculate

(a) the effective resistance of the circuit.

(b) the current in each lamp in the circuit.

(c) the total current in the circuit.

7. A battery of resistance 0.10 ohm is connected in series with an ammeter of resistance 0.5 ohm. The ammeter registers 10 amperes. When a resistance is placed in series with the ammeter the current drops to 4 amperes.

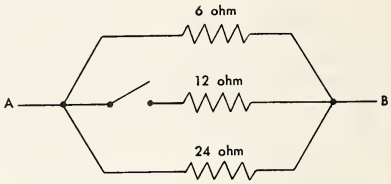
(a) Draw a diagram of the circuit described.

(b) Find the voltage of the battery.

(c) Find the value of the added resistance.

8. The difference of potential between the ends of a certain resistance coil when a current of 0.36 ampere is passed through is 1.2 volts. What resistance must be connected in parallel with the coil so that, with the same total current, the difference of potential will be only 1.0 volt?

9. Three resistances are connected as shown in the diagram and a potential difference of 20 volts is applied between points A and B.



(a) Calculate the total resistance between A and B when the switch is closed.

(b) Find the current in the 6 ohm resistance with switch open.

(c) Find the current in the 12 ohm resistance with switch closed.

10. A cell with a potential difference of 2 volts and negligible resistance sends a current through two resistances of 6 ohms and 9 ohms connected in parallel. In series with the cell is a third resistance of 2 ohms. Calculate the current in the 6 ohm resistance.

11. A current of 4.0 amperes is passed through a resistance of 2.0 ohms in series with a parallel combination of 4.0 ohms and 6.0 ohms. Calculate

(a) the current in each of the parallel resistances.

(b) the potential difference across the whole circuit.

CHAPTER 26 CHEMICAL EFFECTS OF ELECTRIC CURRENT

V : 40 ELECTROLYSIS

All chemical compounds are composed of two or more elements. The elements are composed of atoms as described in Section V:12. Frequently when atoms unite, electrons are transferred from one kind of atom to the other. The atoms which lose electrons become charged positively and the others negatively. These charged particles are called **ions**. The oppositely charged ions attract each other to form **ion-pairs**. However, the total number of positive and negative charges has not been altered, so that the ion-pairs formed are neutral. When substances formed in this way are dissolved in water, some of these particles dissociate into separate positive and negative ions. Compounds which form ions in solution are capable of carrying electric current and are called **electrolytes**. Examples of good electrolytes are solutions of acids bases and salts. Many other substances do not ionize when in solution and so do not conduct electricity. These are classed as **non-electrolytes**. Sugar, alcohol and distilled water are examples of these. Ordinary water usually contains dissolved salts which make it a weak electrolyte. It is for this reason that one can receive a severe electric shock while standing in water or on a damp floor.

Shortly after the discovery of current electricity by Galvani and the construction of the first voltaic cells, experimenters like Sir Humphrey Davy of England and Svante Arrhenius of Sweden investigated the decomposition of water by electricity, or as we speak of it now, the electrolysis of water. Davy showed that in the decomposition of water, the volume of hydrogen produced is double that of oxygen. His most striking discoveries were the breaking apart by electricity of the alkalis, caustic soda and caustic potash. Arrhenius explained these phenomena by his theory of ionization which assumes that in solutions of electrolytes there is at least a partial dissociation of the dissolved substances into separate ions. It was not until 1834 that Faraday introduced the term **anode** for the positive plate and **cathode** for the negative plate in an electrolytic cell (Fig. 26:1). The negatively charged ions which are attracted to the anode became known as **anions**, and the positively charged ions which are attracted to the cathode as **cations**. When compounds dissociate in solution, metals and hydrogen form cations while non-metals and most chemical radicals become anions.

A typical electrolytic cell consists of two conducting-plates or electrodes immersed in an electrolyte. The anode is

connected to the positive terminal of a battery or generator and becomes positively charged while the cathode is connected to the negative terminal and becomes negatively charged. Anions will move to the anode where they give up their surplus electrons, are neutralized, and released as neutral atoms. These electrons flow from the anode, through the connecting wire to the battery terminal. At the same time cations move to the cathode where they receive electrons and became neutral atoms. Electrons move from the negative battery terminal to the cathode to replenish the

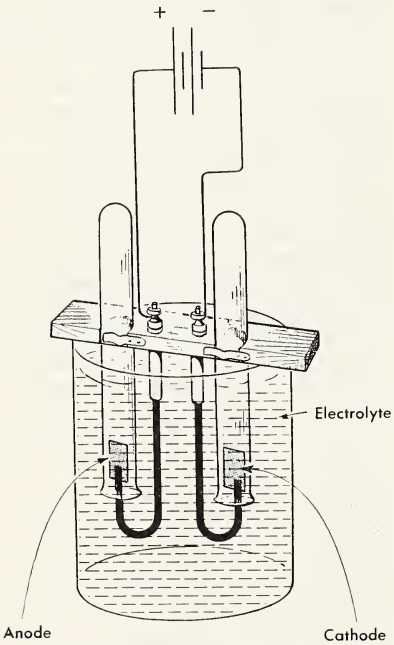


Fig. 26:1 Electrolytic Cell as Used in the Electrolysis of Water.

supply. Thus we have electrons moving from the negative battery terminal to the cathode, through the electrolyte by way of the ions to the anode, and back to the positive terminal of the battery. The electrolyte is decomposed by the electric current. This process is known as **electrolysis.**

V : 41 ELECTROLYSIS OF WATER

Water may be decomposed readily in a simple electrolytic cell (Fig. 26:1), or in the Hoffman water voltameter (Fig. 26:2), by the passage of a direct current through it (Chap. 31, Exp. 25).

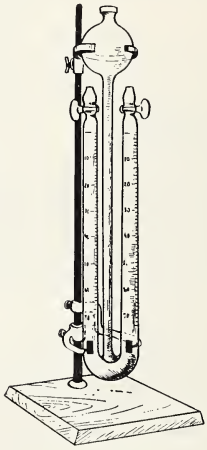


Fig. 26:2 Hoffman Water Voltameter.

A small amount of sulphuric acid (about 10% of the total volume) is added to the water to make it a better electrolyte. The anode and cathode are made of platinum which is unaffected by the electrolyte and is a good conductor of electricity.

In solution the acid is highly dissociated into positive hydrogen ions (H^+) and negative sulphate ions (SO_4^{--}).

$$H_2SO_4 \rightleftarrows 2H^+ + SO_4^{--}$$

The water is slightly dissociated into positive hydrogen ions and negative hydroxyl ions (OH^-):

$$H_2O \rightleftarrows H^+ + OH^-.$$

When the voltage is applied to the electrodes the following reactions occur:

At the Cathode

1. The positive hydrogen ions are attracted to the negative cathode.
2. Each hydrogen ion is neutralized by gaining an electron from the cathode and becomes a hydrogen atom:

$$H^+ + 1e \rightarrow H^\circ$$

3. The hydrogen atoms immediately combine in pairs to form molecules of hydrogen gas which escape as bubbles:

$$H^\circ + H^\circ \rightarrow H_2.$$

At the Anode

1. The negative sulphate and hydroxyl ions are attracted to the positive anode.
2. The hydroxyl ions are discharged in preference to the sulphate ions. Each hydroxyl ion gives up an electron to the anode to become a neutral hydroxyl group.

$$OH^- - 1e \rightarrow OH^\circ$$

3. Pairs of hydroxyl groups then combine to form water and an atom of oxygen.

$$OH^\circ + OH^\circ \rightarrow H_2O + O^\circ$$

4. The oxygen atoms immediately combine in pairs to form molecules of oxygen gas which escape as bubbles.

$$O^\circ + O^\circ \rightarrow O_2$$

As the ions are discharged more water dissociates into ions. The sulphuric acid remains in the electrolyte throughout the process and only the water is decomposed, producing two volumes of hydrogen for every one volume of oxygen.

The electrons given up by the hydroxyl ions at the anode are propelled through the external circuit by the battery to the cathode where an equivalent number of electrons is taken up by the hydrogen ions. This constitutes the current in the external circuit. The movement of the ions to the oppositely charged electrodes within the electrolyte completes the circuit (Sec. V:40).

V:42 ELECTROLYSIS OF COPPER SULPHATE SOLUTION

If copper sulphate solution is used as the electrolyte and carbon rods as the anode and cathode, copper will be deposited at the cathode soon after the voltage is applied (Chap. 31, Exp. 26).

In solution the copper sulphate is highly dissociated into positive copper ions (Cu^{++}) and negative sulphate ions (SO_4^{--}).

$$Cu\,SO_4 \rightleftarrows Cu^{++} + SO_4^{--}$$

The water is slightly dissociated into positive hydrogen ions (H^+) and negative hydroxyl ions (OH^-).

$$H_2O \rightleftarrows H^+ + OH^-$$

When the voltage is applied to the electrodes the following reactions occur:

At the Cathode

1. The copper ions and the hydrogen ions are attracted.
2. The copper ions are discharged in preference to the hydrogen ions. Each copper ion takes two electrons from the cathode and becomes a neutral copper atom.

$$Cu^{++} + 2e \rightarrow Cu^\circ$$

3. The copper atoms are deposited on the carbon rod.

At the Anode

1. The sulphate ions and the hydroxyl ions are attracted.
2. The reactions are exactly the same as in the electrolysis of water (Sec. V:42), in which oxygen bubbles were formed.

Commercial use has been made of such a process in the electroplating industry (Sec. V:45), in which copper is used as the anode and the object to be plated as the cathode. Also, in the purification of various metals, a bar of impure metal

is used as the anode, pure metal as the cathode and a solution of a salt of the same metal as the electrolyte. Only the pure metal is transferred from the anode to the cathode where bars of pure metal are obtained. The impurities are left in the electrolytic cell.

V : 43 LAWS OF ELECTROLYSIS

From your experimental work on electrolysis it will be apparent that there is a close connection between the current strength used and the amount of material that is decomposed (Chap. 31, Exp. 27). It will also be readily noted in the previous examples that the greater the time that the current flows, the greater the amounts of water decomposed or copper deposited. Further, it is not difficult to show that a greater mass of silver than of copper will be deposited using the same current for the same length of time. These observations were made as long ago as 1834 by Faraday who formulated **Faraday's Laws of Electrolysis** as follows:

1. The amount of chemical change produced (i.e., the amount of any substance deposited) by an electric current is proportional to the quantity of electricity passed (Quantity = Current × Time.)

2. The amounts of different substances deposited by the same quantity of electricity are proportional to their equivalent weights. (The equivalent weight of a substance is the weight of the substance deposited by 96,400 coulombs.)

The number of grams of various elements liberated by one ampere in one second is called the electrochemical **equivalent** of the element.

Electrochemical Equivalents	
Aluminum	0.000093
Chlorine	0.000368
Copper	0.000329
Hydrogen	0.0000105
Magnesium	0.000126
Oxygen	0.0000829
Potassium	0.000405
Silver	0.001118
Sodium	0.000238
Zinc	0.000339

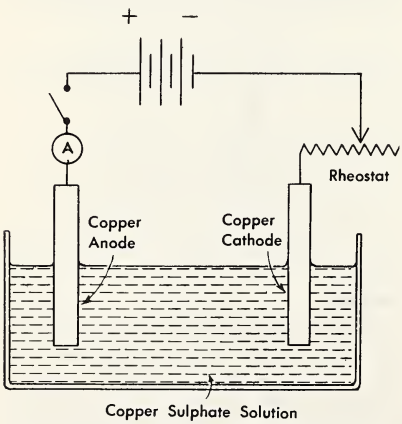


Fig. 26:3 Copper Voltameter Circuit.

V : 44 THE COPPER VOLTAMETER

The internationally accepted definition of the ampere is based on the deposition of metal at the cathode of an electrolytic cell or voltameter. Silver was selected as the standard, since the relatively large amount of silver deposited in a short time enables a greater degree of accuracy in weighing, and because silver is very resistant to oxidation. **The international ampere** is defined as that current which, when passed through a solution of silver nitrate in accordance with given specifications, deposits silver at the rate of 0.001118 gm. per second.

While silver is the best substance for accurate results, a copper voltameter is satisfactory for determining current strength in elementary work (Chap. 31, Exp. 28). In this experiment both anode

and cathode should be copper and the electrolyte copper sulphate solution. The circuit is adjusted so that a small current flows. The cathode should be thoroughly cleaned with fine emery paper, washed and dried. It is then carefully weighed. Next the circuit is connected, as in Fig. 26:3, and the current is allowed to flow for exactly twenty minutes. The cathode is removed, dipped in alcohol or ether and allowed to dry by evaporation. It is then carefully reweighed. The current may be calculated as in this example.

Example

Initial weight of cathode = 5.52 gm.
Final weight of cathode = 5.71 gm.
∴ Weight of copper deposited = 0.19 gm.
Time of current flow = 20 min. = 1200 sec.
Electrochemical equivalent of copper = 0.000329
In 1200 sec. weight of copper deposited = 0.19 gm.

$$\therefore \text{In 1 sec. weight of copper deposited} = \frac{0.19}{1200} = 0.000158 \text{ gm.}$$

Current flowing when 0.000329 gm. copper is deposited in 1 sec. = 1 amp.

$$\text{Current flowing when 1 gm. copper is deposited in 1 sec.} = \frac{1}{000329} \text{ amp.}$$

$$\text{Current flowing when .000158 gm. copper is deposited in 1 sec.} = 0.000158 \times \frac{1}{0.000329} = 0.48 \text{ amp.}$$

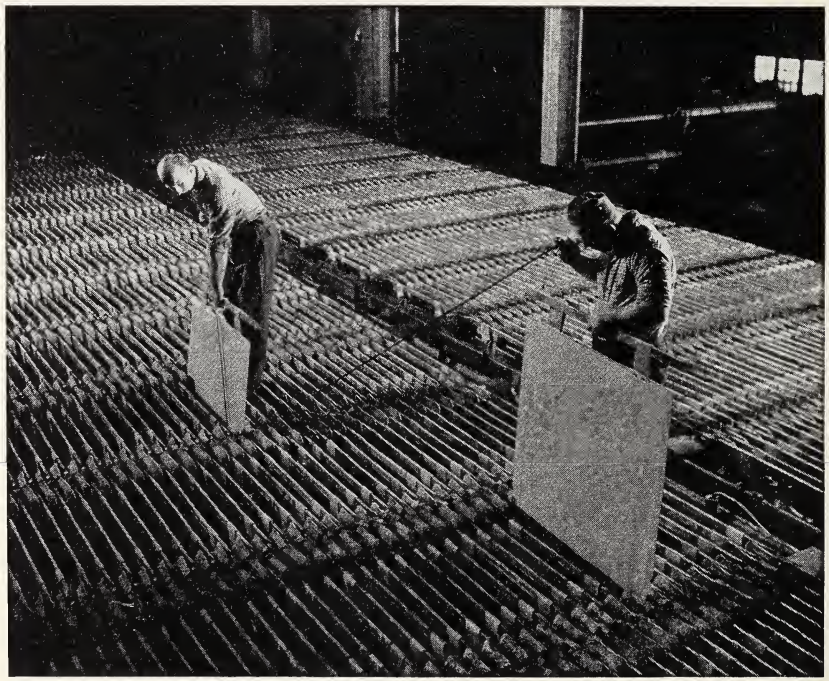
∴ The current strength is 0.48 amp.

V : 45 ELECTROPLATING

Electroplating is an important industrial process designed to improve the appearance, or increase resistance to corrosion, of various metals. It consists of covering the metal with a thin layer of silver, chromium, copper, etc., by electrolysis. The article to be plated serves as the cathode and a solution of a compound of the metal to be deposited makes up the electrolyte (Chap. 31, Exp. 29). Before plating, the object must be thoroughly cleaned of rust, grease, etc. This is usually accomplished by treatment with abrasives followed by rinsing in strong acid, then strong alkali, then weak acid again, and finally distilled water. In order to obtain a fine long-lasting deposit a small current over a long time interval must be used.

Special platings require modifications in the process. For example, silver plating is usually preceded by copper plating to give a suitable base. In copper plating better results are obtained if a little sulphuric acid is added to the electrolyte. Chromium plating directly on another metal leaves small openings like pin-holes in the surface so that corrosion may begin below the chromium layer. To avoid this the base metal is often lightly coated with nickel before the chromium is applied.

Electroplating has also been applied to the printing industry in the reproduction of pages of type and illustrations, a process called electrotyping. An impression of the original is made in wax or plastic. This mould is covered with graphite or metallic powder to serve as a conductor



International Nickel Co. of Canada

Industrial Electroplating. By Electrolysis These Metal Plates are Being Coated with a Thin Layer of Copper.

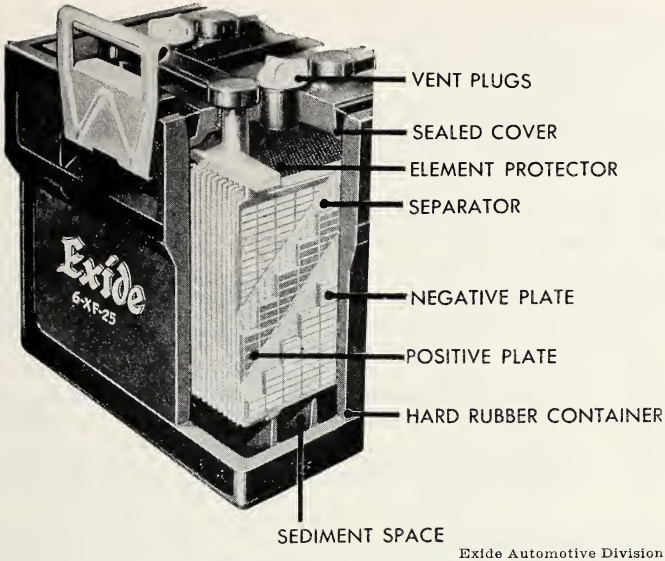
and is then used as the cathode in a copper or nickel electrolytic cell. The metal deposited on it is stripped off, backed with a metal of low melting-point to strengthen it and is then ready for use. This reproduction can be used over and over again and is readily stored for later editions.

V : 46 THE LEAD-ACID STORAGE BATTERY

When the simple voltaic cell (Sec. V:23), and the dry cell (Sec. V:25), become discharged they must be discarded and replaced by new cells. Cells of this type are classified as **primary cells.** The lead storage cell differs from these in that once its chemical energy has been exhausted, the cell may be restored to its original condition by electrical means. Such cells are called **secondary cells.** The familiar lead-acid storage battery used in the electrical system of many automobiles consists of six secondary cells connected in series to provide approximately 12 volts. Chemical energy is stored in the active materials of the plates and in the electrolyte when current is passed through during charging. This chemical energy is transformed into electrical energy as the cells are discharged in providing current in a circuit (Chap. 31, Exp. 30).

(a) Structure of a Cell

Several positive plates, consisting of



Exide Automotive Division

Fig. 26:4 Structure of a Lead-Acid Storage Battery.

lead peroxide forced into a strong grid of lead alloy, are joined to each other by metal strips (Fig. 26:4). Between each of these, and at the ends, are negative electrodes of spongy lead. These are connected by metal strips and kept from touching the positive plates by wood separators. The plates are contained in a moulded, hard rubber case holding the dilute sulphuric acid which serves as the electrolyte.

(b) Discharging the Cell

As the cell is used to provide the E.M.F. which causes current to flow in a circuit, it becomes discharged. The sulphuric acid combines with the porous materials of the plates and the following chemical reaction occurs:

negative plates		positive plates		electrolyte		both plates		diluted electrolyte
lead	+	lead peroxide	+	sulphuric acid	→	lead sulphate	+	water

As the two plates become coated with the same material the potential difference decreases. Simultaneously, the removal of sulphuric acid from the electrolyte and the formation of water causes dilution of the acid in the cell. Thus, discharged cells are indicated by a lowering of the P.D. of the cell and a decrease in the specific gravity of the electrolyte. A fully charged cell should have a P.D. of approximately 2.2 volts, and

a specific gravity of 1.275 to 1.300. It is ready for recharging when the specific gravity falls to 1.185.

(c) Recharging the Cell

In order to recharge the cell direct current from a rectifier or some other source must be passed through the cell in the direction opposite to that of discharge. The chemical reactions in the cells are reversed:

both plates	diluted electrolyte	positive plates	negative plates	electrolyte
lead sulphate +	water	→ lead peroxide +	lead +	sulphuric acid

Thus, the plates are again made dissimilar and the P.D. increases to 2.2 volts. At the same time water is used up and sulphuric acid is produced by the reaction, so the specific gravity of the electrolyte increases.

The charging and discharging reactions may be summarized as:

negative plates	positive plates	electrolyte	both plates	diluted electrolyte
lead +	lead peroxide +	sulphuric acid ⇄ (discharge / charge)	lead sulphate +	water

(d) Care of Storage Batteries

1. Keep the battery clean and dry.
2. Do not allow the battery to discharge below specific gravity 1.185.
3. Keep the electrolyte above the level of the wood separators by addition of distilled water.
4. Do not allow a fully discharged cell to stand in this condition for more than a few days before charging.

(e) Battery Rating

The life of a battery is rated in ampere-hours, i.e., amperes × hours. For example, a battery rated at 100 ampere-hours would be capable of delivering 5 amperes for 20 hours, or 12.5 amperes for 8 hours, etc. In general, the greater the number of plates per cell, the greater the ampere-hour capacity of the battery.

(f) Uses of Storage Batteries

Storage cells are frequently used to provide a source of E.M.F. for extended periods of time, as in some radio transmitters and receivers. They are used in the starting circuits of automobiles and aircraft, for auxiliary power supplies for telephones, trains, submarines and ships and for emergency lighting-systems.

V : 47 QUESTIONS

A

1. (a) Define: ion, electrolyte, non-electrolyte, electrolytic cell, anode, cathode, anion, cation, electrolysis.
(b) Outline Arrhenius' theory of ionization.

2. Explain how the electrolyte completes the circuit in electrolysis.

3. In the electrolysis of water describe:

(a) the condition of the water and the sulphuric acid before the voltage is applied.

(b) what happens in the electrolyte at the moment when the voltage is applied.

(c) the reactions that occur at (i) the cathode (ii) the anode.

4. Explain the electrolysis of copper sulphate solution.

5. Describe how electrolysis may be used in

(a) silver plating
(b) refining of copper
(c) electrotyping.

6. (a) State Faraday's Laws of Electrolysis.
(b) Define electrochemical equivalent.

7. (a) Define an ampere in terms of the deposition of metal at the cathode of an electrolytic cell or voltameter.
(b) Why is this definition more acceptable than that based on Ohm's Law?
(c) Why was silver selected as the international standard rather than copper?

8. (a) Describe the construction of a lead-acid storage cell.
(b) What transformations of energy take place in (i) charging, (ii) discharging a lead-acid cell?
(c) Give word equations describing the reactions as a lead-acid cell is (i) charged, (ii) discharged.
(d) How may the condition of charge of such a storage battery be determined?

9. (a) Define ampere-hour.
(b) What determines the ampere-hour capacity of a battery?
(c) What precautions should be observed in caring for a storage battery?

B

1. What weight of (a) copper (b) silver will be deposited in 3 hours by a current of 1 ampere?

2. What weight of (a) copper (b) silver will be deposited in 4 hours by a current of 2.0 amperes?

3. What weight of (a) oxygen (b) hydrogen would be liberated in the electrolysis of water by a current of 2.0 amperes flowing for 4 hours?

4. What current would deposit 0.1 gm. of silver in 8 hours?

5. A constant current is passed through a copper voltameter for exactly 20 minutes and it is found that 0.500 gm. of copper is deposited on the cathode. Calculate the strength of the current.

6. An ammeter connected in series with a silver voltameter reads 1.50 amperes. In 50 minutes the increase in weight of the cathode is 4.947 gm. What is the error in the ammeter reading?

7. A copper voltameter and a water voltameter are connected in series with a direct current supply. In 25 minutes 0.09 gm. of copper is deposited on the cathode of the copper voltameter.

(a) What current is flowing in the circuit?
(b) What mass of hydrogen is liberated in the water voltameter?

8. A current of 2 amperes is passed through a copper voltameter. Copper is deposited evenly on the cathode which has an area of 66 sq. cm. Find the thickness of the layer when the current has been flowing for 30 minutes. (Density of copper = 9.0 gm. per c.c.)

9. The anode of a copper voltameter is made of impure copper, and the particles of impurity detach themselves and fall to the bottom of the cell as electrolysis continues. A current of 2.0 amperes flows for 1 hour and 40 minutes. At the start the anode weighs 85.69 gm. and at the end 81.37 gm. Find the mass of copper dissolved from the anode and the mass of impurity released.

10. (a) If four 2 volt lead-acid cells, each of 0.1 ohm internal resistance, are connected in series with a conductor of 3.6 ohms resistance, what current would flow?
(b) How long would this current continue to flow if the battery has a capacity of 30 ampere-hours?

CHAPTER 27 MAGNETIC EFFECTS OF ELECTRIC CURRENT

V : 48 ELECTROMAGNETIC EFFECT

In 1820, Hans Christian Oersted, professor of Physics at the University of Copenhagen, made a discovery that has made possible most of the modern advancements in electrical knowledge. He observed that a wire carrying an electric current deflected a compass-needle. Further experiments established that whenever a current was passing through a conductor a magnetic field was set up around it.

It is possible to investigate this magnetic field by passing a conductor through a piece of cardboard, as shown in Fig. 27:1. When the switch is closed and iron filings are sprinkled lightly over the cardboard, gentle tapping will cause the filings to arrange themselves in concentric circles with the wire as centre. Thus the pattern of the lines of magnetic force becomes apparent. The direction of these lines of force may be determined

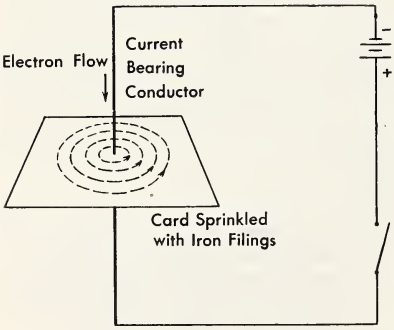


Fig. 27:1 Magnetic Field about a Conductor.

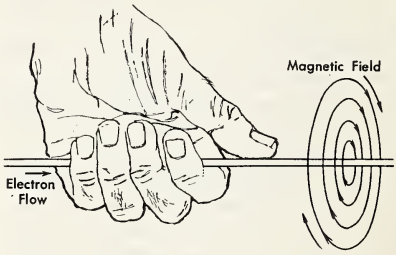


Fig. 27:2 Left Hand Rule to Determine the Direction of the Magnetic Field about a Conductor.

by placing a number of small magnetic compasses on the cardboard. The N-poles of the compasses indicate that the lines go in a counter-clockwise direction about the wire (Chap. 31, Exp. 31).

It is apparent, then, that if the direction of current is known, the direction of the lines of force about a conductor may be determined as follows: Grasp the conductor with the left hand with the thumb extended in the direction of the electron flow (— to +). The fingers

will now point in the direction in which the lines of magnetic force encircle the wire. This statement is called the **Left-Hand Rule** (Fig. 27:2). Conversely, this rule may be used to determine the direction of the electron flow if the direction of the lines of force is known.

V : 49 MAGNETIC FIELD ABOUT A HELIX

A single turn of wire (Fig. 27:3) is called a **loop** or **coil**. A series of such

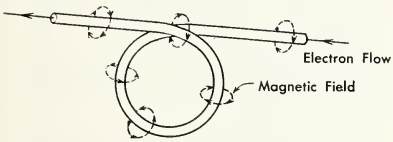


Fig. 27:3 Magnetic Field about a Loop Carrying Electric Current.

loops in a wire (Fig. 27:4) is referred to as a **helix** or **solenoid**. If a conductor is formed into a single loop, the lines of

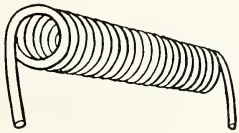


Fig. 27:4 A Helix or Solenoid.

magnetic force which surround the wire will pass through the centre of the loop as shown. Note that the magnetic field inside the loop will be more dense than outside since the lines of force are crowded into a smaller area.

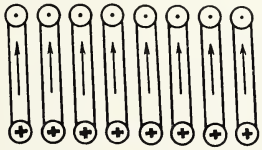


Fig. 27:5 Cross-sectional View of a Helix with the Front Half Removed. The Direction of Electron Flow is Indicated.

When considering the magnetic field about a helix, it is convenient to represent it as in Fig. 27:5. The helix is shown in cross-section with the front half removed. The electron flow is up the back section of the turns and down the front. In the diagram, electron flow is indicated by a dot (.) representing the head of an arrow and a cross (+) representing the tail. Fig. 27:6a shows the lines of magnetic force around a few turns of wire. The Left-Hand Rule will confirm the

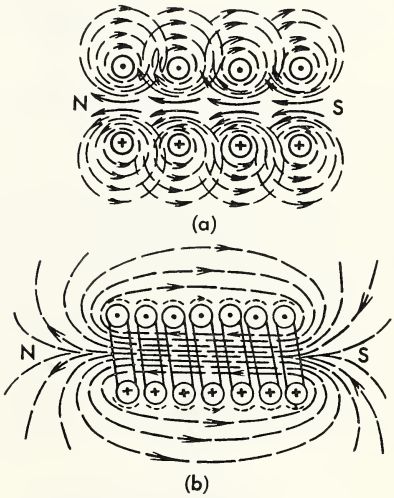


Fig. 27:6 The Lines of Magnetic Force Around the Individual Turns of Wire in a Helix as Shown at (a), Combine to Form the Resultant Field Shown at (b).

direction of these lines. Between the turns the forces are in opposite directions and so tend to cancel each other out. In the centre of the coils the forces act in the same direction and are very concentrated. On the outside of the helix the forces also reinforce each other to give us the field represented in Fig. 27:6b. Note the similarity between this

pattern and that formed by a bar magnet (Sec. V:4).

The existence of this field may be readily proved by inserting a helix, carrying current, in a slit in a piece of cardboard (Fig. 27:7). Iron filings will

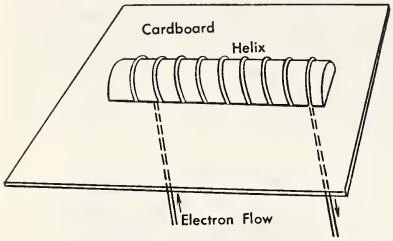


Fig. 27:7 Apparatus Used to Demonstrate the Field of Force about a Helix Carrying Electric Current.

indicate the pattern of the magnetic field (Chap. 31, Exp. 32). The polarity of the field may be determined by testing with a compass-needle. From this information a simple rule may be confirmed: Grasp the helix in the left hand so that the fingers extend in the direction the electrons are flowing around the turns. The extended thumb will then point towards the N-pole of the helix (Fig. 27:8). This may be called the

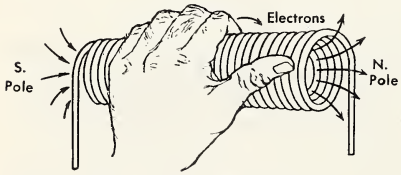


Fig. 27:8 Helix Rule.

Left-Hand Rule for the Helix or, to avoid confusion with other rules, simply the **Helix Rule.**

V : 50 ELECTROMAGNETS

If a bar of iron is placed in the centre of a coil of wire through which a current is flowing, the iron will become magnetized. The elementary magnets of the iron become aligned in such a direction as to reinforce the magnetic field of the coil. Thus the iron core greatly strengthens the magnetic field. Such an arrangement is known as an **electromagnet.** Soft iron makes the most satisfactory core, since a temporary magnet is produced. When the current in the coil is stopped the magnetism of the core is lost in a short time. An increase in the number of turns in the coil or an increase in the strength of the electric current flowing through it will result in a more powerful electromagnet (Chap. 31, Exp. 33).

Electromagnets have been designed in a variety of shapes to meet many needs. The iron clad type is widely used where strong magnetic fields are desirable as

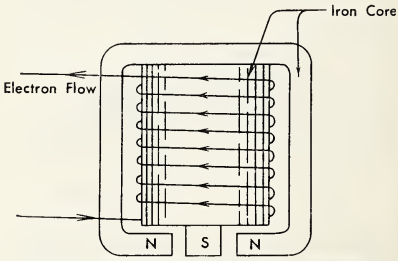


Fig. 27:9 Iron-Clad Electromagnet.

for a lifting magnet for scrap iron or in radio loudspeakers. The iron core not only passes through the centre, but almost completely surrounds it as shown in Fig. 27:9.

The horseshoe electromagnet (Fig. 27:10) is used in such devices as earphones, telephone receivers, electric bells and electric buzzers. The **electric bell** (Fig. 27:11) consists of a gong, a horseshoe electromagnet, soft iron armature and contact screw arranged in a circuit as shown. When the switch is closed

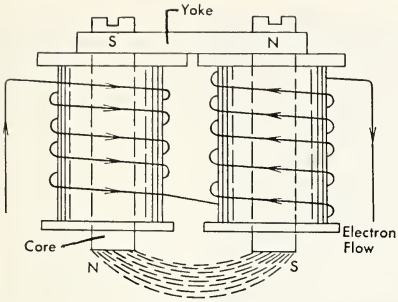


Fig. 27:10 The Horseshoe Electromagnet.

current flows in the winding of the electromagnet, causing the armature to be attracted. As the armature moves away from the contact screw the circuit is broken. The electromagnet loses its magnetism and the armature is pulled back to the contact point by the spring. This completes the circuit and the action is repeated. Thus, the hammer will vibrate against the gong as long as the switch is depressed and a continuous ringing is produced.

Electromagnets are being used more and more to protect circuits carrying large currents. **Magnetic circuit breakers** employ a switch which is opened by the magnet if the current becomes too strong. A simple circuit is shown in Fig. 27:12. The student should trace the path of the electrons and explain the action of the circuit breaker.

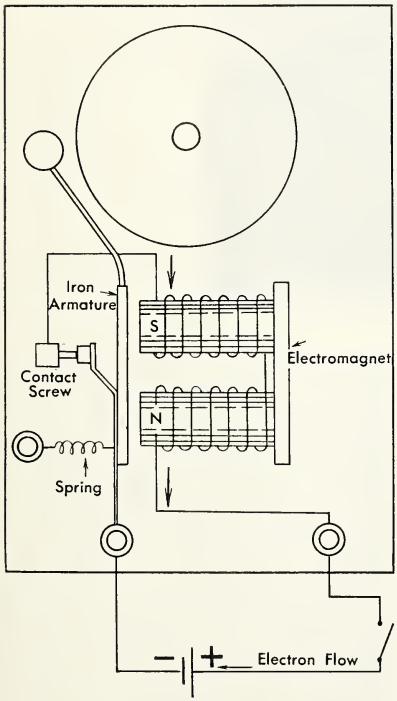


Fig. 27:11 The Electric Bell.

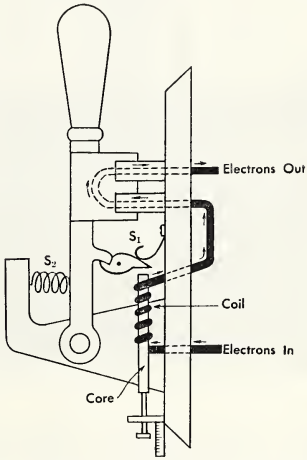
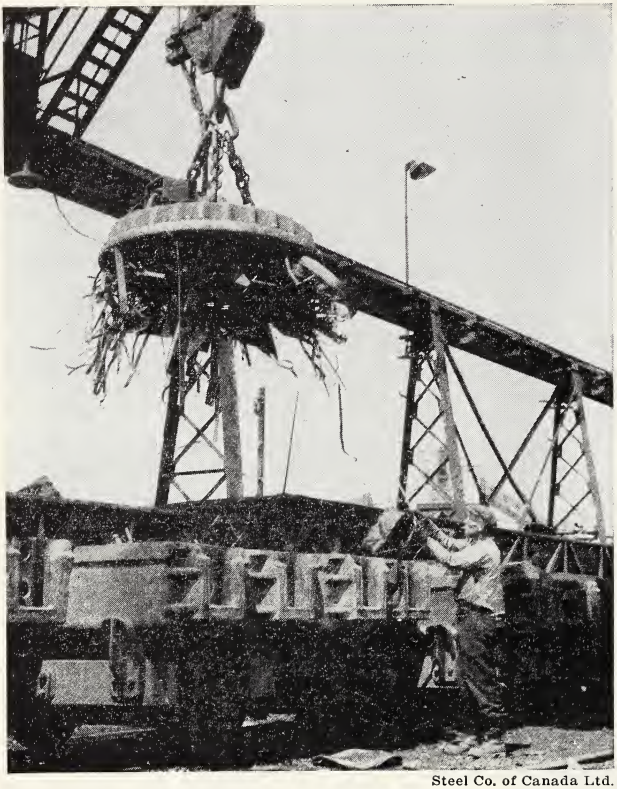


Fig. 27:12 Magnetic Circuit Breaker. If current becomes too great, core is pulled upwards by magnetism of the coil, tripping the catch held by S_1. Spring S_2 pulls up the knife switch breaking the circuit.

The **automobile generator cut-out relay** is a magnetic switch which opens and closes the circuit between the generator (Sec. V:63) and the battery



An Electromagnet Used for Lifting Scrap Iron.

Steel Co. of Canada Ltd.

(Sec. V:46). It serves to connect the generator to the battery when the generator is operating at charging speeds and to open the circuit when the generator stops or slows down to prevent the battery from discharging back through the generator. A simple circuit is shown in Fig. 27:13.

The cut-out relay has two windings assembled on the same soft iron core. The shunt winding (dotted) is connected in parallel with the generator so that, when the generator starts to operate, the potential difference created causes a current to flow through the winding. This produces a magnetic field strong enough to pull the armature toward the core, and the circuit is closed as the contact points meet. Current then flows from the generator to the battery and back through "ground", passing through the series winding in such a direction as to add to the magnetism holding the armature down.

When the generator slows down, the voltage produced by the generator becomes less than the battery voltage. Thus, a current begins to flow in the reverse direction through the series winding but continues to flow in the same

direction in the shunt winding. The magnetic fields of the two windings are now in opposite directions and so tend to cancel each other. The armature is pulled upward by spring tension to open

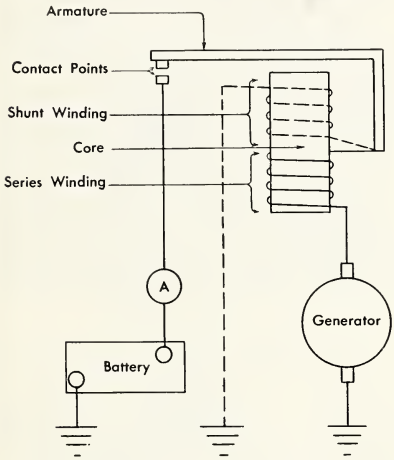


Fig. 27:13 Automobile Generator Cut-Out Relay.

the contact points and the circuit is broken between the battery and the generator.

V : 51 THE GALVANOSCOPE

The galvanoscope is a simple device used to determine the directions and comparative strengths of electric currents. It consists of several coils having varying numbers of turns of wire (Fig. 27:14). The current is made to pass over a compass-needle in one direction and under the needle in the opposite direction. In this way the magnetic effect of the current is magnified and the compass-needle will be deflected. By applying the Left-Hand Rule (Sec. V:48), the direction of current may be determined. By noting the amount of deflection of the needle a rough com-

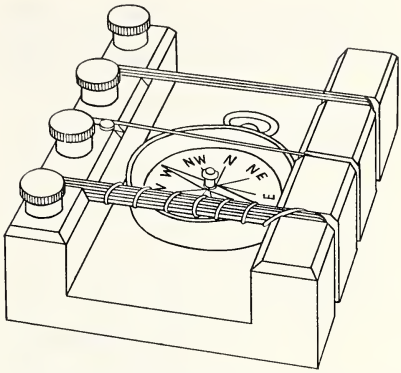


Fig. 27:14 A Simple Galvanoscope.

parison of current strengths may be made. For weak currents the coils with many turns will be used and for strong currents the coils with few turns are satisfactory (Sec. V:50). This instrument has been largely replaced by more sensitive and more accurate current-measuring devices.

V : 52 THE MOTOR PRINCIPLE

In experiment 34, chapter 31, a conductor *AB* was suspended between the poles of a strong permanent magnet as shown in Fig. 27:15. When a heavy current was sent through the conductor from a storage battery or similar source, the conductor was pushed aside. When the current was reversed, the conductor was thrust in the opposite direction. Thus we see that a conductor carrying current in a magnetic field is acted upon by forces which cause the conductor to move.

The magnetic field between the poles of the permanent magnet may be represented as shown in Fig. 27:16(a). The current in the conductor sets up a magnetic field as in Fig. 27:16(b). A cross-section of the conductor is shown in Fig. 27:16(c). When the conductor is in the permanent magnetic field, as in Fig.

27:16(d), the lines of force from both the conductor and the permanent magnet are in the same direction on the

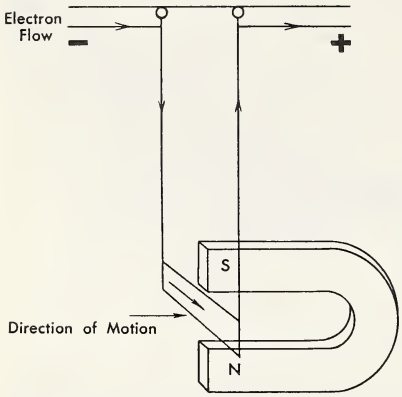


Fig. 27:15 Action of a Conductor Carrying Electric Current in a Magnetic Field.

right and in opposite directions on the left. Thus the lines tend to be crowded on the right side, while on the left they cancel each other. Since lines of magnetic force are like stretched elastic bands (Sec. V:4), they try to straighten themselves and consequently, push the conductor to the left. Similarly, if the electron flow in the conductor is reversed, the motion will be in the opposite direction.

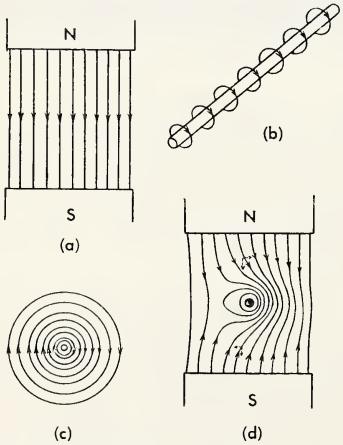


Fig. 27:16 The Motor Principle.

If now conductor *AB* (Fig. 27:15), is replaced by a single loop *ABCD* (Fig. 27:17), section *AB* will be moved toward the left by the combined forces of the permanent magnetic field and the electromagnetic field, while section *CD* will be thrust toward the right. Thus, the loop will set itself so that the plane of the coil will become perpendicular to the direction of the lines of force of the permanent magnet. This behaviour may be more simply explained if we consider

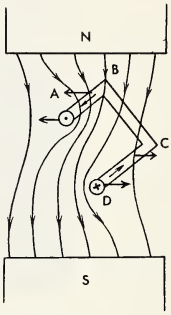


Fig. 27:17 Action of a Loop Carrying Electric Current in a Magnetic Field.

the loop to be a form of helix. The Helix Rule (Sec. V:49), indicates that the loop, when carrying current, will have an N-pole and an S-pole. Following the Law of Magnetism (Sec. V:2), the N-pole of the loop will be attracted to the S-pole of the permanent magnet while the S-pole of the loop will face the N-pole of the magnet.

V : 53 THE D'ARSONVAL GALVANOMETER

The D'Arsonval Galvanometer is a

sensitive instrument designed to detect the presence of small direct currents of electricity. It also serves to determine

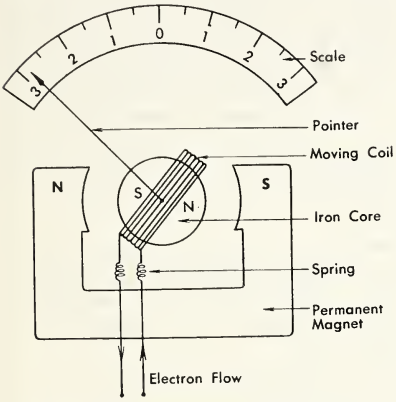


Fig. 27:18 A Simple Galvanometer.

the direction and compare the strengths of such currents.

The simplest form of this type of galvanometer is shown in Fig. 27:18. It consists of a permanent horseshoe magnet and a coil of wire which is free to swing between the poles of the magnet. A stationary soft iron core is mounted inside the coil to concentrate the lines of force. Springs attached to the coil serve to conduct the electrons into and out of the coil and also to bring the coil to rest in a position where the plane of the coil faces away from the poles of the magnet, as shown in the diagram. As current passes through the coil it will turn, so that the N-pole of the coil is toward the S-pole of the magnet, and the S-pole of the coil is toward the N-pole of the magnet (Sec. V:52). This movement is restricted by the springs. The amount of turning is indicated by the attached pointer moving across a calibrated scale. The stronger the electric current through the coil, the greater the magnetic field produced, and so the higher the reading on the scale. This moving-coil type of meter is the basis of most standard electrical measuring instruments in common use.

V : 54 AMMETERS AND VOLTMETERS

Ammeters and voltmeters are instruments designed to measure electric current and potential difference respectively. They are essentially galvanometers of the moving-coil type (Sec. V:53), modified by the addition of suitable resistances. Their scales are calibrated to read directly in amperes or volts.

(a) Ammeters

The wire winding on the moving coil of an ammeter must be very fine and light to allow the necessary freedom of movement. Such a conductor cannot carry a large current without undue heating (Sec. V:71), and consequent melting of the wire. The movable coil of such an instrument is rarely allowed to carry more than 0.05 amperes.

If the ammeter is to be used to mea-

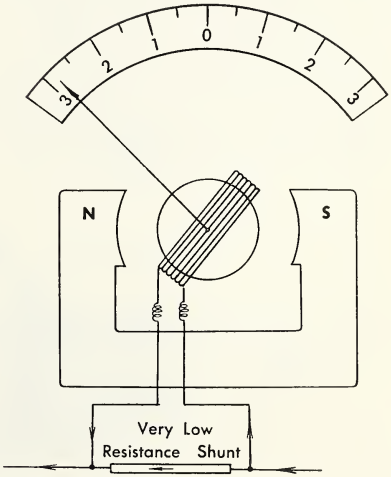


Fig. 27:19 Ammeter Connected in Series.

sure higher currents than this the current must be divided so that no more than 0.05 amperes will flow through the moving coil, and the rest of the current will be carried around the coil through **a shunt** connected in parallel with the instrument (Fig. 27:19). Such a shunt must have a very low resistance and be accurate over a wide range of temperatures.

To measure the current in a circuit the ammeter must be connected in series. As a result, all the current, or a known fraction of the total current, will pass through the instrument coil. In order to avoid affecting the total current in the circuit, the resistance of the ammeter must be very low. If the ammeter were accidentally connected across the circuit, a high current would flow through it and the instrument would be "burned out". To avoid this a fuse (Sec. V:72) should be connected in series with the ammeter.

Example

A galvanometer has a resistance of 5 ohms and gives a full-scale deflection with a current of 0.05 amperes. What value of shunt resistance must be used to convert it to an ammeter reading up to 5 amperes?

Current to be carried by ammeter = 5 amp.

Current to be carried by galvanometer = 0.05 amp.

∴ Current to be carried by shunt = 5 — 0.05 = 4.95 amp.

Resistance of galvanometer = 5 ohms.

∴ Potential difference across galvanometer =

$$0.05 \times 5 = 0.25 \text{ volts } (V = IR)$$

∴ Potential difference across shunt = 0.25 volts (parallel connection)

∴ Resistance of shunt to be used =

$$\frac{0.25}{4.95} = 0.05 \text{ ohms } \left(R = \frac{V}{I}\right)$$

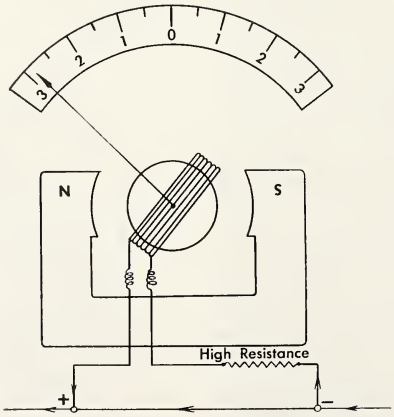


Fig. 27:20 Voltmeter Connected in Parallel.

(b) Voltmeters

Since a voltmeter is used to measure the potential difference between two points in a circuit, it must be connected in parallel with the circuit between these points. Therefore, a voltmeter must have a very high resistance to avoid drawing a large current. As a result the total current in the circuit will not be affected significantly. A galvanometer may be converted to a voltmeter by the addition of a high resistance in series with the moving coil (Fig. 27:20).

Example

A galvanometer has a resistance of 5 ohms and gives a full-scale deflection with a current of 0.05 amperes. What value of series resistance must be used to convert it to a voltmeter reading up to 5 volts?

Potential difference across voltmeter = 5 volts
Current through voltmeter = 0.05 amp.

$\therefore$ Resistance of voltmeter $= \dfrac{5}{0.05} = 100$ ohms $\left(R = \dfrac{V}{I}\right)$

Resistance of galvanometer = 5 ohms

$\therefore$ Series resistance to be added = 100—5 = 95 ohms.

V : 55 THE ELECTRIC MOTOR

The electric motor is studied in experiment 35, chapter 31, using a St. Louis motor (Fig. 27:21). In order to understand its operation consider an electromagnet mounted on an axis so that it is free to rotate between the poles of a magnet (Fig. 27:22). If a current is passed through the electromagnet so as to produce an S-pole at the top, as shown, the S-pole will be attracted by the N-pole of the stationary field. Similarly the N-pole of the electromagnet will be attracted by the S-pole of the stationary magnet. These forces cause the electromagnet, which serves as the motor **armature**, to rotate. The momentum of this armature causes it to rotate so that the S-pole of the armature passes slightly beyond the N-pole of the magnet.

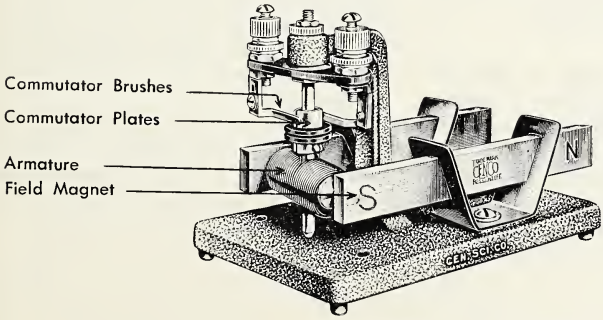


Fig. 27:21 St. Louis Motor.

Central Scientific Co. of Canada Ltd.

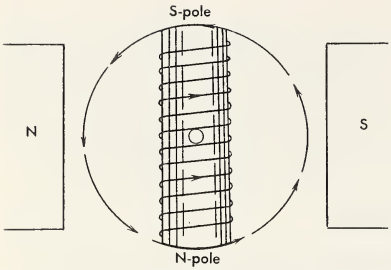


Fig. 27:22 Electric Motor. The Armature is Free to Rotate Between the Poles of the Magnet.

If the current in the armature windings could be reversed at this instant, the polarity of the armature would change and repulsion and attraction would carry the armature through another 180° (Fig. 27:23). Successive reversals of current

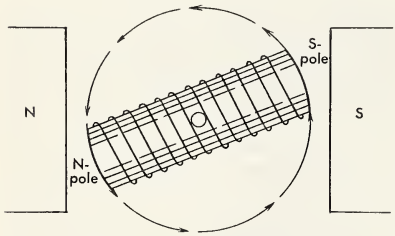


Fig. 27:23 Electric Motor. The Poles Reverse in this Position so Armature Continues to Rotate.

and consequent changes of armature polarity cause the rotation to continue. Such a reversal of current can be caused by the use of a **commutator** (Fig. 27:24). The armature wires are attached to two segments of good conducting material which are insulated from each other. As the armature rotates the segments of the commutator also rotate. Connection to the commutator segments is made by a pair of brushes, one leading the electrons in (—) and the other out (+). At exactly the correct instant, segment R makes contact with brush B_1 causing the electrons to flow through the armature. One-half turn later, segment R makes contact with brush B_2 as segment S contacts brush B_1, etc. Thus the commutator serves to reverse the direction of electron flow with every 180° rotation of the armature.

The magnetic field in which the armature turns is usually provided by an

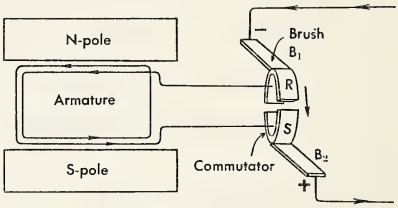


Fig. 27:24 Electric Motor. The Commutator Reverses the Direction of Electron Flow Every 180°.

electromagnet, since such a magnet may be made more powerful than a permanent type. Its windings are called the field coils to differentiate them from the armature coil. The field coils may be in series or in parallel with the armature coil, depending on the motor characteristics desired. A more advanced text should be consulted if greater detail is required.

The motor described here operates on direct current only, and thus is seldom used. However, it serves to illustrate the principle of operation of all electric motors, including those operating on alternating current.

V : 56

QUESTIONS

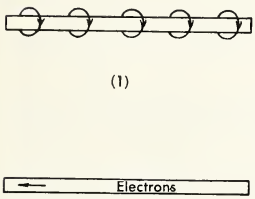
A

1. (a) Draw diagrams showing the lines of magnetic force for (i) a straight wire (ii) a single turn of wire when carrying an electric current. Indicate clearly on each diagram the direction of the electron flow and of the magnetic field.

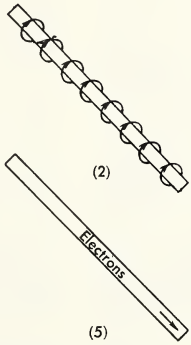
(b) State the Left-Hand Rule.

(c) Indicate the direction of the current in wires (1), (2) and (3) in which the direction of the lines of force is shown.

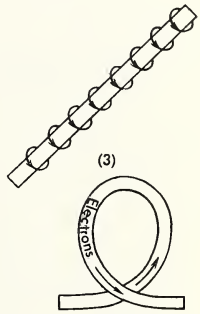
(d) Indicate the direction of the lines of force around wires (4), (5) and (6) carrying a current.



(1) (4)



(2) (5)

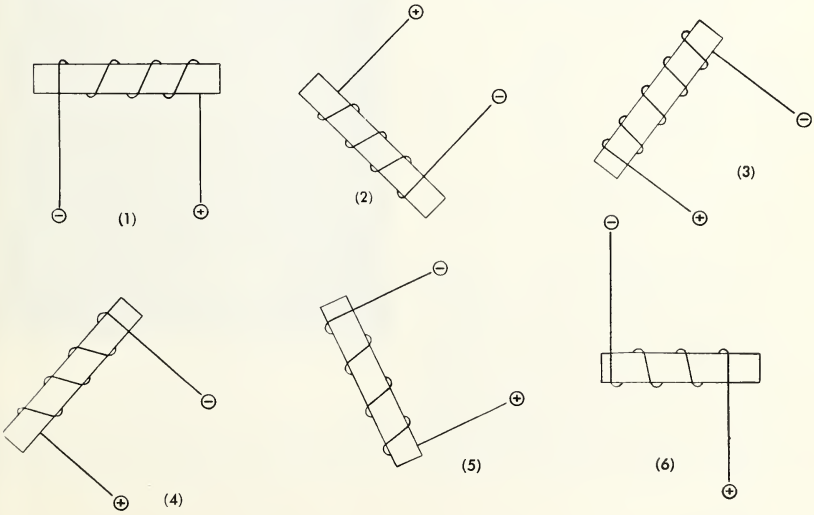


(3) (6)

2. (a) On a diagram of a solenoid indicate the direction of electron flow and the magnetic field surrounding it.

(b) State the Helix Rule.

(c) On the following diagrams mark the direction of the current and the polarity of the solenoids.



3. (a) Why is soft iron, rather than steel, used as the core in most electromagnets?
(b) How may the strength of an electromagnet be increased?

4. (a) Make a fully labelled diagram of an electric bell connected in a circuit.
(b) With the aid of this diagram describe the operation of an electric bell.

5. (a) What is the purpose of an automobile generator cut-out relay?
(b) Describe its operation.

6. (a) What is the purpose of a galvanoscope?
(b) Describe and explain the operation of a galvanoscope.

7. (a) State the motor principle.
(b) Make a labelled diagram of a simple moving-coil galvanometer and explain how its operation employs the motor principle.
(c) What precaution should be ob-observed when a galvanometer is connected in a circuit?
(d) How may a galvanometer be modified to convert it into (i) an ammeter (ii) a voltmeter?

8. Make a labelled diagram of a simple D.C. motor and describe its operation.

B

1. A galvanometer has a resistance of 10 ohms and gives a full-scale deflection with a current of 0.04 ampere. What value of shunt resistance must be used to convert it to an ammeter reading up to (a) 5 amperes (b) 50 amperes (c) 500 amperes.

2. A galvanometer has a resistance of 2 ohms. It gives a full-scale deflection with a current of 0.01 ampere. What value of shunt resistance must be used to convert it to an ammeter reading to 10 amperes?

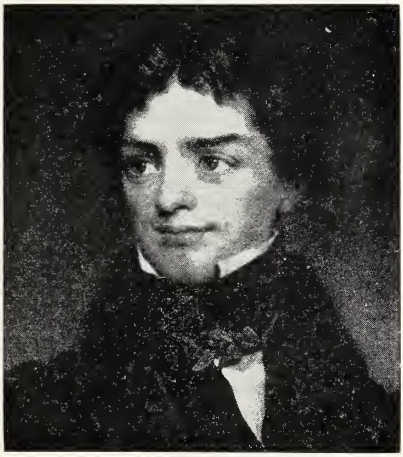
3. What value of series resistance must be added to convert the galvanometer of question 1 to a voltmeter reading up to (a) 5 volts (b) 50 volts (c) 500 volts?

4. What value of resistance must be connected in series with the galvanometer of question 2 to convert it to a voltmeter reading up to 100 volts?

CHAPTER 28 ELECTROMAGNETIC INDUCTION

V : 57 THE STORY OF FARADAY

Michael Faraday was one of the greatest experimental scientists the world has ever known. He was born in England in 1791 and, after a very ordinary education, became an apprentice to a book-



University of Toronto

Michael Faraday

binder. He read every scientific book which passed through his hands and quickly became well educated. He impressed the great chemist, Sir Humphrey Davy, so much that at the age of twenty-one he became his assistant at the Royal Institution. Within twelve years he was made a director of the Institution.

From the time that Oersted demonstrated the magnetic effect of an electric current Faraday dreamed of the converse effect, the production of electricity from magnetism. After many unsuccessful experiments he finally produced a momentary current in a coil of wire wound on an iron ring by starting and stopping a current in another coil wound on the same ring (Fig. 28:1).

With this small beginning Faraday began a series of experiments on electro-

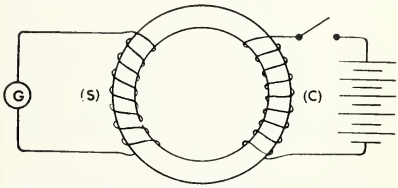


Fig. 28:1 Electricity from Magnetism.

magnetism that eventually led to his invention of the dynamo. The services of Faraday were in great demand by industrial firms but he refused great wealth in order to devote his talents to scientific discovery. Honours of all kinds were showered upon him but he remained the humble scientist and experimenter to the end, devoting his time and

energy to discovery. When all else is forgotten, he will be remembered as the father of the electric current that serves our homes, offices, factories and communities. Some of his other discoveries, such as the methods of liquefying gases, making optical glass, the isolation of benzine, and the like, are not remembered so well even though of great importance.

Although he was never one to seek publicity his name has become immortal because of his contributions to humanity through physics and chemistry.

V : 58 CAUSE OF AN INDUCED CURRENT

It is a simple matter to demonstrate, as Faraday did, that, just as electrons in motion can set up a magnetic field, a magnetic field in motion can cause a flow of electrons. Three such experiments are described in chapter 31, experiment 36.

If a galvanometer is connected to the terminals of a solenoid and a bar magnet or an electromagnet is held above the solenoid (Fig. 28:2), no current is obtained. When the magnet is thrust into the centre of the coil, i.e., the strength of the magnetic field is increased, the galvanometer needle is momentarily deflected from its centre position. The galvanometer needle returns to the zero position when the magnet remains stationary in the solenoid, i.e., while the strength of the magnetic field remains constant. When the magnet is withdrawn quickly from the solenoid, the strength of the magnetic field decreases, and the galvanometer needle is again deflected, but this time in the opposite direction. It is apparent, then, that a flow of electrons originated each time the magnet was moved. This is called **induced current**, and the effect caused by the changing magnetic field around a conductor is called **electromagnetic induction.**

For an induced current to flow in the circuit there must, of course, be an electromotive force in the circuit (Sec. V:26). This induced E.M.F. is caused by the changing magnetic field about the conductor.

Similarly, in the circuit used by Faraday (Fig. 28:1), when the switch in circuit containing the battery and the primary coil (C) was opened, the electron flow was stopped. Thus, the magnetic field about the primary coil decreased rapidly to zero. This changing magnetic field cut the turns of the secondary coil (S) in the circuit and an E.M.F. was induced. When the switch was closed, current flowed in the primary circuit and as the magnetic field increased from zero to a maximum, an E.M.F. was induced again in the secondary circuit, causing a current to flow in the opposite direction.

From these experiments we may conclude that an induced E.M.F. is caused by the changing magnetic field about the conductor.

V : 59 MAGNITUDE OF INDUCED E.M.F.

In experiment 37, chapter 31, it will be observed that, if the magnet is slowly plunged into and withdrawn from the solenoid, there will be slight deflection of the galvanometer needle. If the action is repeated more and more rapidly, it will be seen that the amount of deflection is directly proportional to the speed of movement of the magnet. Thus, we may conclude that the strength of the induced current is proportional to the speed at which the magnet is moved or the **E.M.F. induced in a circuit is proportional to the rate of change of the magnetic field cutting the conductor.**

If a magnet is thrust first into a coil of few turns and then, at the same speed, into a coil of many turns, and the deflection of a galvanometer in the

circuit is noted, it will be found that a stronger induced current flows in the coil having the larger number of turns. Therefore, it is evident that **the E.M.F. induced in a circuit is proportional to the number of turns of the conductor cut by the varying magnetic field.**

When a powerful electromagnet with an iron core is substituted for the bar magnet in the experiment described above it will be observed that, with the rate of movement and the number of turns in the coil remaining constant, the deflection of the galvanometer needle is greatly increased. It is apparent, then, that **the E.M.F. induced in a circuit is proportional to the strength of the changing magnetic field.**

V : 60 DIRECTION OF AN INDUCED CURRENT

The direction of an induced current is studied in experiment 38, chapter 31. Here, the direction of the current is noted when (a) the N-pole of a magnet is thrust into the coil; (b) the N-pole is

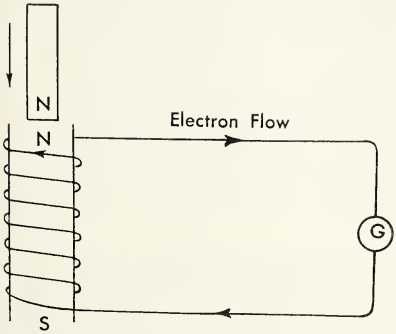


Fig. 28:2 Induced Current as the Bar Magnet is Plunged into the Solenoid.

withdrawn; (c) the S-pole is inserted; (d) the S-pole is withdrawn. As the N-pole enters the solenoid (Fig. 28:2) a current is induced which produces an N-pole at the end of the solenoid where the magnet enters. This N-pole repels the N-pole of the magnet and opposes the motion of the magnet. As the N-pole of

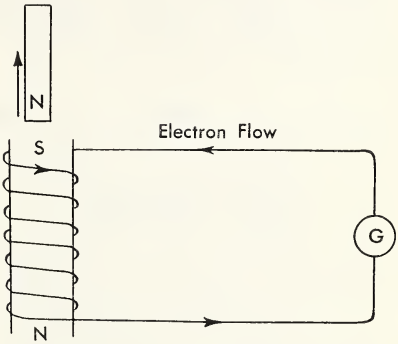


Fig. 28:3 Induced Current as the Bar Magnet is Withdrawn from the Solenoid.

the magnet is withdrawn from the coil (Fig. 28:3) the induced current is in such a direction as to produce an S-pole at the same end of the solenoid. The attraction of this S-pole of the solenoid for the N-pole of the magnet tends to oppose the withdrawal of the magnet. Similar results may be found when the electromagnet is used. These effects are summarized in **Lenz's Law** which states: **The direction of an induced current is such that the magnetic field which it produces opposes the motion or change that induces the current.**

Because of their importance, primary and secondary currents require special treatment. It was noted (Sec. V:58), that secondary currents are in opposite directions when the primary is opened compared to when it is closed. It is demonstrable that the primary and secondary currents are in the same direction when the primary circuit is opened (at the "break") and in the opposite direction when it is closed (at the "make"). The idea of opposing mag-

netic fields is carried out here in that the induced current, while flowing in the same direction as the primary, attempts to maintain the magnetic field that is collapsing. Similarly, at the completion of the primary circuit, the induced current is attempting to oppose a magnetic field which is being built up. It is further to be noted that the induced E.M.F. is greater at the "break" because the induced current tends to strengthen the field of force of the primary.

V : 61 THE EARTH INDUCTOR

The earth inductor is a coil with a diameter of about 18 in., made of several hundred turns of fine insulated copper wire. When the two end leads of the coil are connected to a galvanometer and the inductor is rapidly rotated through 360°, the galvanometer needle will be seen to swing first to one side and then to the other (Chap. 31, Exp. 39A). This action continues as long as the inductor is rotated.

In Fig. 28:4, as the coil rotates clockwise, *A* downward and *B* upward, little cutting of the lines of force occurs and a small E.M.F. will be developed at first. As it nears the position at right angles to the first, much cutting of the lines of force

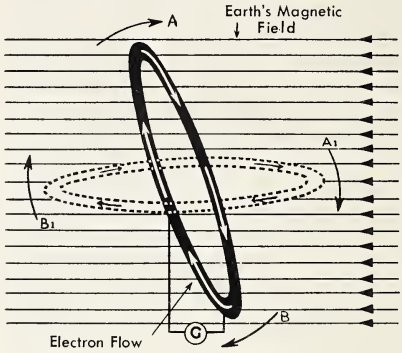


Fig. 28:4 Earth Inductor.

occurs, and the E.M.F. produced will be larger. Throughout this 90° of rotation the induced E.M.F. has been built up from zero. It will be obvious that the E.M.F. will gradually decrease to zero in the next 90°. Throughout this rotation of 180°, the E.M.F. has gone from zero to a maximum and back to zero again (Fig. 28:5). The direction of the current has been constant. All this time

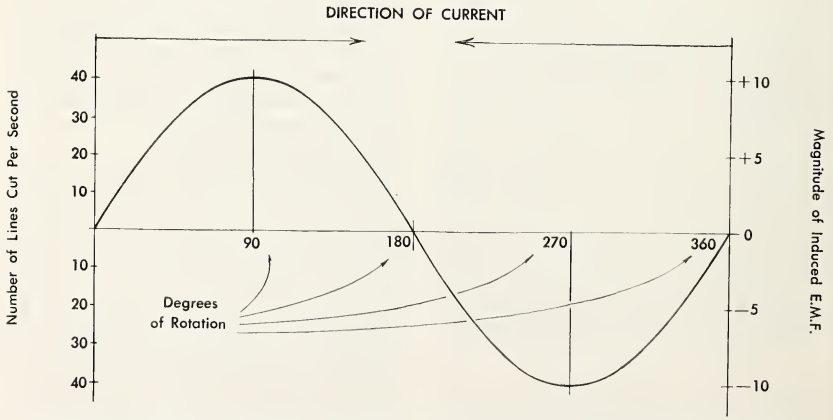


Fig. 28:5 Graph of Current Produced as Earth Inductor is Rotated Through 360°.

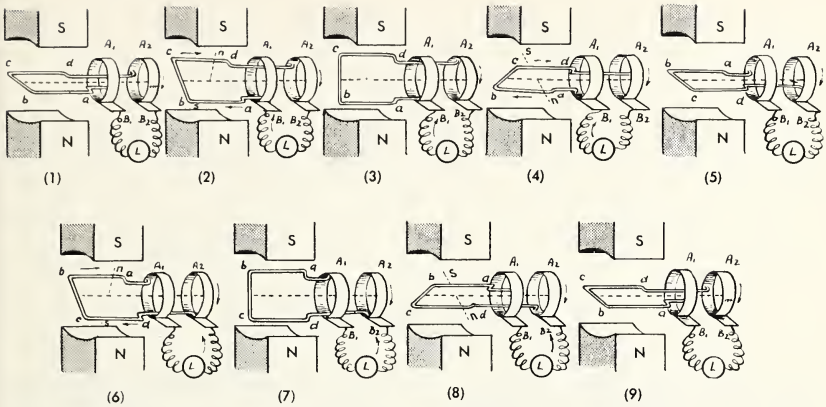


Fig. 28:6 Simple Alternating Current (A.C.) Generator.

the magnetic field of the induced current has been opposing the motion causing it (Lenz's Law). Rotation through the next 180° in which A will move up and B down will result in the same cycle of events as before except that the direction of the current will be reversed. The energy required to overcome the opposition of the fields of force is transformed into electrical energy.

While the earth inductor itself is of no practical value it does permit a preliminary study of the generation of electricity by induction. This simple knowledge has made possible the development of all the many forms of electric generators which supply power for modern living.

V : 62 THE ALTERNATING-CURRENT GENERATOR

As indicated in section V:61, mechanical energy may be used to produce electrical energy. A device used for this purpose is called a **generator** or **dynamo.**

A simple generator (Fig. 28:6) consists of a coil of wire called an armature which is made to rotate between the poles of a magnet (Chap. 31, Exp. 39B). To facilitate connections to the rotating armature, slip rings (A_1, A_2) are connected to each end of the coil and rotate with it. Contact is made by metal or carbon brushes (B_1, B_2) which connect the coil with the external circuit containing the lamp (L).

As the coil rotates in the direction shown in the diagram, it cuts the magnetic field between the pole-pieces (S, N) of the magnet and a current is induced in the conductor. In position (1) the sides *ab* and *cd* of the conductor are momentarily moving parallel to the lines of magnetic force so there is no cutting and no induced E.M.F. Therefore no electrons will flow. In position (2) the coil is cutting an increasing number of lines of force so the induced E.M.F. is increasing. Electrons flow in the direction *abcd* so as to produce an N-pole and an S-pole in the coil which will oppose its motion (Lenz's Law). Electrons are now leaving the slip ring B, passing through the lamp, and returning to A. In position (3) the conductor is cutting the maximum number of lines of force and the induced E.M.F. and induced electron flow are at a maximum. As the

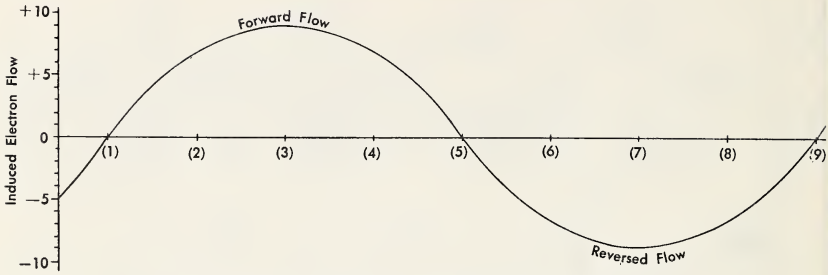


Fig. 28:7 Graph of Alternating Current.

coil reaches position (4) the electron flow is decreasing and, in position (5) as the motion is parallel to the lines of force once more, it ceases entirely. In (6) the electron flow builds up again but this time in the direction *dcba* so that electrons leave slip ring *A*, pass through the lamp, and return through *B*. The current again reaches a maximum in (7), decreases in (8), and falls to zero in position (9). Thus, during one complete rotation of the coil, the induced current starts at zero, increases to a maximum, falls to zero, increases to a maximum in the opposite direction, and again falls to zero. These changes are summarized in Fig. 28:7. A current with such characteristics is said to be an **alternating current** (A.C.) and one cycle has been described above.

Alternating current is provided by all hydro-electric installations. Those who have lived in, or visited, 25-cycle power areas will have noticed the rapid flickering of the lights. This is caused by the reversal of current flow occurring 25 times per second. When the number of reversals is increased to 60 times per second as in 60-cycle power, this flickering is not noticeable. Very few areas of the world still use this 25-cycle power.

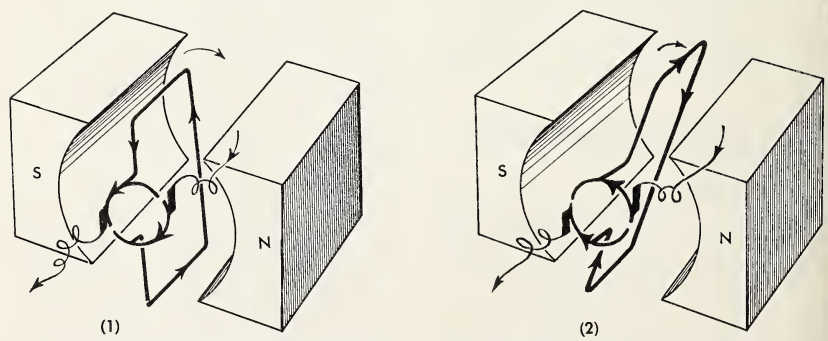


Fig. 28:8 The Action of the Commutator.

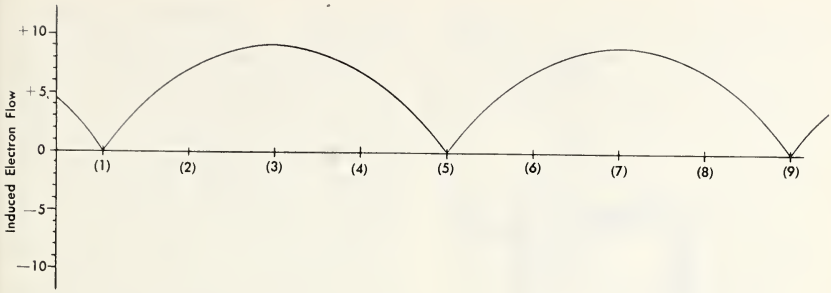


Fig. 28:9 Graph of Direct Current.

V : 63 THE DIRECT-CURRENT GENERATOR

When electrons flow continuously in one direction it is said to be a **direct current.** Such current is required for special installations such as electroplating. In order to obtain direct current from an A.C. generator, a **commutator** must be used in place of the slip rings (Chap. 31, Exp. 39B). For a single-coil generator as described in section V:62, the commutator consists of a collecting-ring made of two segments or commutator bars insulated from each other. Each bar is connected to a terminal of the coil (Fig. 28:8).

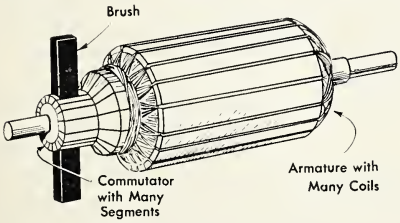


Fig. 28:10 Armature of a Commercial D.C. Generator

The brushes are so placed that they rest on the insulating material between the bars at the instant when the electrons are about to reverse direction. Thus the commutator bars change brushes just as the electron flow reverses so that the current flowing through the external circuit is always in the same direction (Fig. 28:9).

The current from a single turn of wire is clearly a pulsating current. To eliminate this the armature of a commercial generator consists of many such coils each with its commutator arranged around the shaft (Fig. 28:10). Such an arrangement will give a more continuous flow of current, since some of the coils will always be cutting the magnetic lines of force. Such generators are used in automobiles, electrical systems in remote places, direct-current generating systems in schools, hospitals, etc., and for electroplating and electro-purification of metals.

V : 64 TRANSFORMERS

Transformers are used to change the voltage in an A.C. circuit as required. A transformer consists of two separate coils of insulated wire, the primary and secondary coils, wound on the same soft iron core (Fig. 28:11). Alternating currents from a generator flow through the windings of the input or **primary coil.** As the current changes in intensity and direction, the magnetic field surrounding the coil changes as well. Thus lines

of magnetic force of changing strength and direction are made to cut the turns of the output or **secondary coil.** An alternating E.M.F. is induced in the secondary coil. Since the magnitude of

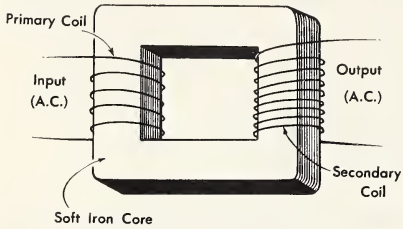


Fig. 28:11 Step-up Transformer.

the induced E.M.F. is proportional to the number of turns of the conductor cut by the changing magnetic field, the strength of the induced voltage may be varied by using a different number of turns in the primary and secondary windings. For any transformer—

$$\frac{\text{Output Voltage}}{\text{Input Voltage}} = \frac{\text{No. of turns on secondary coil}}{\text{No. of turns on primary coil}}$$

A **step-up transformer** has more turns on the secondary coil than on the primary coil and so serves to increase or "step up" the voltage. A **step-down transformer** has more turns on the primary coil than on the secondary and so serves to decrease or "step down" the voltage.

In section V:75, it will be established that the power of an electric current = the number of volts × the number of amperes. Obviously the power of the secondary current must equal the power of the primary current (except for a very small decrease owing to conversion to heat). Thus, if a step-up transformer causes a voltage rise, there must be a corresponding fall in the current.

Students will be familiar with the small step-down transformers used to operate electric trains, electric bells and electric janitors around the home. Some other uses of the transformer will be described in the sections that follow.

Example

A transformer is to be used to provide 6 volts to operate an electric door-bell on a 120 volt circuit. If the primary coil has 2000 turns, how many turns should be on the secondary coil?

Output voltage = 6 volts
Input voltage = 120 volts
Number of turns on primary = 2000
Number of turns on secondary = x

$$\therefore \frac{\text{Output voltage}}{\text{Input voltage}} = \frac{\text{Number of turns on secondary coil}}{\text{Number of turns on primary coil}}$$

$$\frac{6}{120} = \frac{x}{2000}$$

$$\therefore x = \frac{6}{120} \times 2000 = 100$$

$\therefore$ there should be 100 turns on the secondary coil.

V : 65 THE TELEPHONE

The first telephone was invented by Alexander Graham Bell, a Scottish emigrant to the United States, in 1875, and first used between Brantford and Paris, Ontario. Bell's main interest was in teaching deaf-mutes, but he had many other interests and the telephone was one of the many products of his fertile mind. From his simple instrument has been developed the world-wide communication system that we know to-day.

Star Newspaper Service

Alexander Graham Bell.

The essential parts are the transmitter and the receiver. The **transmitter** (Fig. 28:12) consists of a capsule containing carbon granules (C) connected to a thin metal sheet called the diaphragm (D) on one side and to a carbon block (B) on the other. A current from a battery passes through the granules.

It responds to sound waves as follows: the condensations and rarefactions falling on the diaphragm cause it to vibrate. When the vibrations are transmitted to the carbon granules, they are compressed to a varying degree. This, in turn, causes their electrical resistance to vary and fluctuations in the current strength are produced at the same frequencies as the sounds. This fluctuating current is transmitted to the receiver.

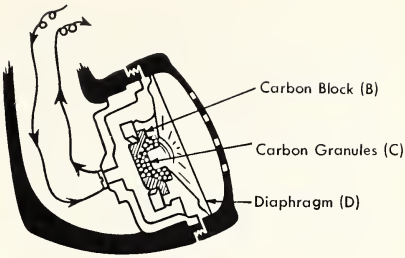


Fig. 28:12 Telephone Transmitter.

As we know so well, the purpose of the receiver is to convert these fluctuating currents into sound again. The **receiver** (Fig. 28:13) consists of a permanent magnet (M) having an electromagnet at the poles. As the fluctuating current caused by the transmitter passes through the coils (CC) of the electro-

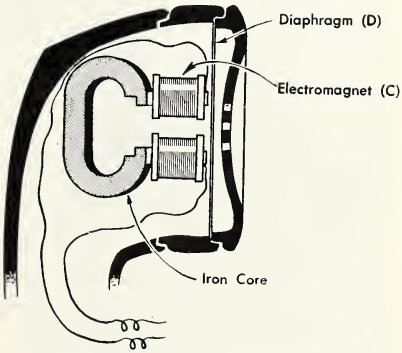


Fig. 28:13 Telephone Receiver.

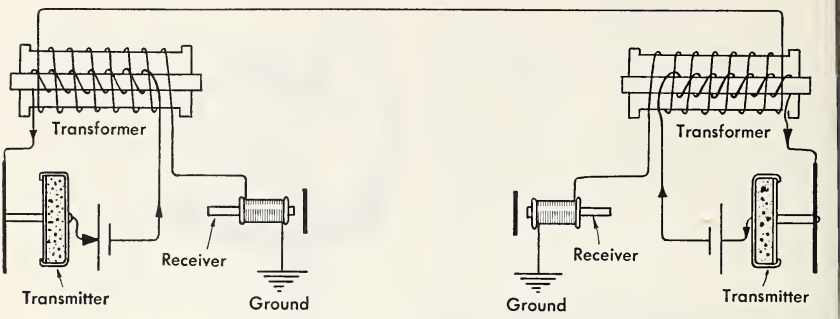
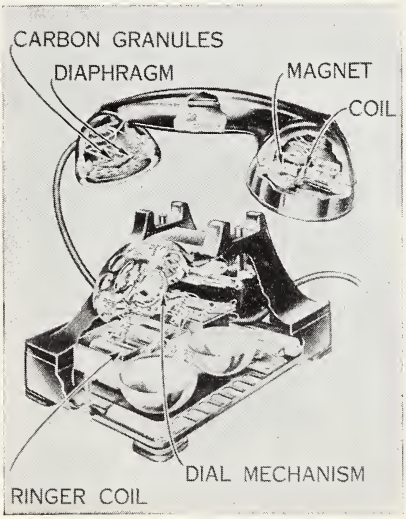


Fig. 28:14 Simple Telephone Circuit.

magnet, the magnetic field is caused to change at the same frequency as the original sound waves. Thus the steel diaphragm (D) is caused to vibrate at this frequency and sound waves almost identical to those at the transmitter are reproduced at the receiver.

If the transmitter and receiver circuits are directly linked, only weak signals will be heard. This is because of the very small changes in resistance in the carbon granules of the transmitter as compared to the total resistance of the circuit. The slight variations in current do not cause enough variation in the receiver electromagnet to give satisfactory reception. To overcome this, the transmitter is connected to the primary winding of a step-up transformer. The secondary coil is connected in the line circuit through which magnified effects are carried to both receivers as shown in Fig. 28:14.



Bell Telephone Co. Canada

The Dial Telephone.

Refinements such as the bell signal, automatic dialing, relays, ultra high-frequency beam wireless, sheathed cables, coaxial cables, and others are employed in the modern system. However, the above still remains the basis for all telephone communication.

V : 66 SELF-INDUCTANCE

It has been observed that when an electric circuit is broken, as when a switch in a house-lighting circuit is turned off, a spark or "electric arc" frequently occurs. This is caused by self-inductance which is explained below.

When a coil of wire of many turns, wound about an iron core, is connected to a battery, the current that begins to flow causes a magnetic field about the wire. As an increasing number of lines of force cut the conductor, an E.M.F.

will be induced in the coil itself causing a current to flow in a direction opposite to the flow of current in the coil (Lenz's Law). Thus the current will build up more slowly than might be expected in such a circuit (Chap. 31, Exp. 40).

When the connection to the battery is broken, the decreasing current causes a decreasing magnetic field about the wires. An E.M.F. causing a current that flows in the same direction as the main current will result. Since this is of relatively high voltage, a definite spark (arc) will be observed. In a circuit, an induced current that opposes any change in the flow of current through it caused by self-inductance is called a **self-induced current.** It is so similar to the inertia of matter that it has been termed electromagnetic inertia. It is an important consideration in all alternating-current equipment design.

V : 67 THE INDUCTION COIL

The induction coil is very like the transformer in construction, as both consist of primary and secondary coils of different numbers of turns of wire wound about a common soft iron core. Whereas the transformer can utilize the changing magnetic field caused by alternating current to step up the voltage, the same operation is impossible with a direct current for lack of changing magnetic field. However, it is possible to obtain high voltage from a low voltage direct current by the use of an induction coil. This is accomplished by continually interrupting the primary current, with the aid of a circuit breaker similar to that in the electric bell (Sec. V:50). This results in a changing magnetic field around the primary which induces a high voltage current in the secondary coil. This device was first invented by Page in the United States in 1836 and later reinvented by Ruhmkorff in Europe in 1851.

The induction coil (Fig. 28:15) consists of a primary coil *A* of a few turns of thick insulated copper wire wound about a soft iron core *B* which is not solid but built up from a bundle of soft iron wires to prevent self-induction effects. Around the primary coil is a secondary coil *C* consisting of many turns of very fine copper wire wound in sections with paraffined-paper insulation between the layers of each section. The primary circuit is completed through

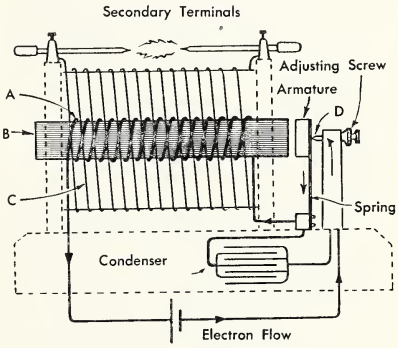


Fig. 28:15 Induction Coil.

a make-and-break device *D*. This consists of a stiff piece of spring steel with a soft iron armature on one side and a platinum (or tungsten) contact on the other. It is normally in contact with the platinum (or tungsten) point on the end of the adjusting screw. As the primary current flows, the core becomes magnetized and attracts the armature, thereby breaking the circuit. The magnetism of the core now collapses and the armature thus released is drawn back by the spring to make contact with the screw. The primary circuit is again complete for the action to be repeated. As the magnetic field of the primary circuit builds up and collapses at each make and break, an alternating induced

E.M.F. is set up in the secondary coil. This E.M.F. may be many tens of thousands of volts and can cause a spark several inches long to pass between the terminals of the secondary coil. One-half of each alternation has a much greater E.M.F. than the other (Sec. V:60). As a result this current usually is viewed as a pulsating direct current. In actual practice the weaker of the two is practically eliminated by the use of a condenser.

Induction coils can be used for operating X-ray tubes, although modern tubes are mainly transformer operated. They are also employed in some forms of laboratory research where moderately high voltages are required, and in the ignition systems of automobiles.

Note: Because of the very large self-inductance of the primary winding, the upbuilding and decay of the primary current are both delayed, and the slower changes in the magnetic field mean correspondingly reduced voltages in the secondary coil. The self-induced forward E.M.F. in the primary circuit at the break causes arcing across the contact points which become considerably worn as a result. To prevent this a condenser *E*, formed from alternate sheets of tin-foil and paraffined-paper, is placed across the make and break, and the self-induced current at break surges into the condenser instead of arcing across the points, thereby producing a very rapid break. The condenser plates, however, are connected through the primary winding, and no sooner is the condenser charged than it discharges through the primary coil, producing a current in it in a direction opposite to the now upbuilding current from the battery. As was noted before (Sec. V:60), the induced current is weaker at the make than at the break. The condenser weakens it still further. Accordingly, the coil produces practically a pulsating, direct current of higher E.M.F. than that of the primary.

V:68 THE AUTOMOBILE IGNITION SYSTEM

The flammable mixture of gasoline vapour and air used in internal combustion engines is ignited by a series of sparks passing across the electrodes of spark plugs fitted into the cylinder heads. These sparks, which are correctly timed for each of the cylinders, are produced by a type of induction coil, the primary of which is connected to the battery through a circuit breaker, while the secondary is connected through a "distributor" to the electrodes of the spark plugs. The scheme of the ignition system, is shown in Fig. 28:16.

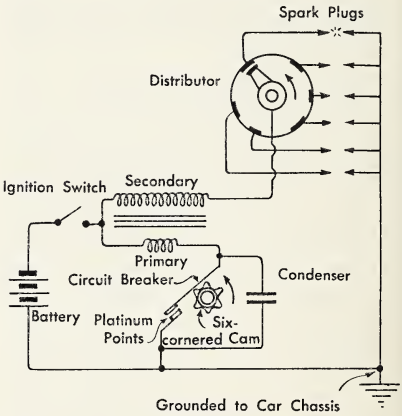


Fig. 28:16 Simple Automobile Ignition System.

The circuit breaker is operated by a cam revolving at half speed and driven from the engine crankshaft. When the platinum points are separated, the resulting change of magnetic field of force produces an induced voltage in the secondary coil. A condenser is connected across the contact points to prevent

arcing (and consequent damage to the points) and to ensure a rapid break as described in the previous section. In order to withstand the high voltages (of the order of 10,000 volts), the leads from the secondary coil to the distributor and spark plugs are covered with thick insulation.

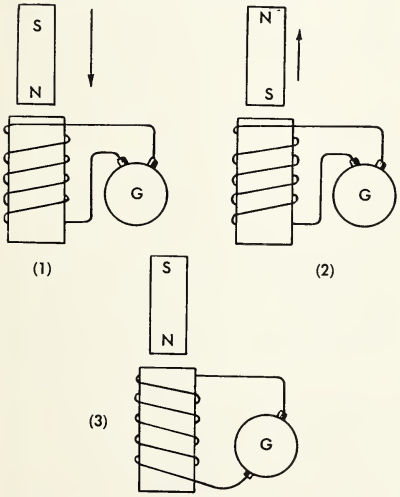
V:69 QUESTIONS

A

1. Read a more complete story of Faraday in a good encyclopedia and write a brief account of his accomplishments.

2. Describe briefly Faraday's method of producing induced current for the first time.

3. (a) What is the cause of an induced current?
(b) What factors affect the magnitude of the E.M.F. induced in a circuit?
(c) State Lenz's Law.
(d) On the following series of diagrams label the direction of the current and indicate the polarity of the upper end of the solenoid.



4. (a) Describe the structure of an earth inductor.
(b) Describe the current produced in the inductor with regard to direction and magnitude as the coil is revolved through 360° in the earth's field.

5. (a) Make a diagram of a simple generator with a single coil of wire rotating between the poles of a permanent magnet. Describe the current produced with regard to magnitude and direction as the coil rotates through 360°.
(b) How is the current taken from the rotating armature and fed into the external circuit?
(c) Describe how a direct-current generator differs from an alternating-current generator.

6. (a) Describe, using simple diagrams, the current produced by (i) an alternating-current generator (ii) a direct-current generator.
(b) What is meant by (i) a single cycle (ii) 60-cycle current (iii) pulsating direct-current?

7. Explain:
(i) the structure
(ii) the action of
(a) a step-up transformer
(b) a step-down transformer.

8. (a) Describe (i) a simple telephone transmitter (ii) a simple telephone receiver with regard to purpose, structure, action.
(b) Describe how transmitter and receiver circuits are linked in order to keep up the strength of signals.

9. What is the effect of self-inductance when a circuit containing a coil of wire is (a) completed (b) broken?

10. Describe a simple induction coil as to (a) purpose (b) structure (c) action (d) uses.

B

1. A transformer is required to provide 6 volts to operate an electric door-bell on a 120 volt circuit. If the primary coil has 1600 turns, how many turns should be on the secondary?

2. A step-down transformer has 2000 turns on the primary and 200 turns on the secondary. If the primary voltage is 22,000 volts, what is the secondary voltage?

3. An electric door-bell transformer has 960 turns on the primary and 80 turns on the secondary. When it is connected to the 110 volt circuit, what voltage is provided for the bell?

4. A generator produces alternating current at 2200 volts. This is supplied through a step-up transformer with a voltage ratio of 1:100 to the transmission lines. This is fed to a step-down transformer of voltage ratio 1000:1.

(a) What is the final voltage?

(b) Draw a simple diagram to show these stages.

5. A generator with an E.M.F. of 550 volts supplies energy to a 2200-volt line. The transformer has 100 turns on its primary winding. How many turns must there be on its secondary?

6. A transformer, used to operate a toy electric train on a 120-volt line, has taps on the secondary to give 12, 8, 6 and 4 volts. If the primary winding has 960 turns, how many turns must there be on the secondary at each tap?

CHAPTER 29 ELECTRICAL ENERGY

V : 70 THE PRODUCTION OF ELECTRICITY

Not many years ago Canada was known throughout the world as an agricultural country. A survey of our exports at the beginning of the twentieth century shows that farm products formed the basis of our economy. In the years preceding the Second World War a gradual swing towards greater industrial expansion could be noted. From those years to the present time the change has been almost phenomenal. Canada has become an industrial nation. Our exports now, while still including a large part of the world wheat supply and other agricultural commodities, have been expanded to take in countless manufactured articles ranging from heavy farm machinery to paper, clothing, electrical devices, chemicals and products of mining and smelting.

Closely connected with these changes has been the marvellous development of Canada's hydro-electric power resources. The energy of falling water has been harnessed to turn the huge turbines which rotate the armatures of large generators (Fig. 29:1). Steam-generating plants have become common in which the energy from coal is utilized. In recent years heat from an atomic pile is being used in the same way. These latter methods provide the alternating current that is so vital to our modern way of life. Millions of horsepower have been made available to turn the wheels of industry across the country and to provide the luxuries of cheap electricity in our homes. Men of foresight have planned for new and greater feats in engineering as they divert the waterways, tunnel through mountains and improve the generators to provide Canada with power for the future.

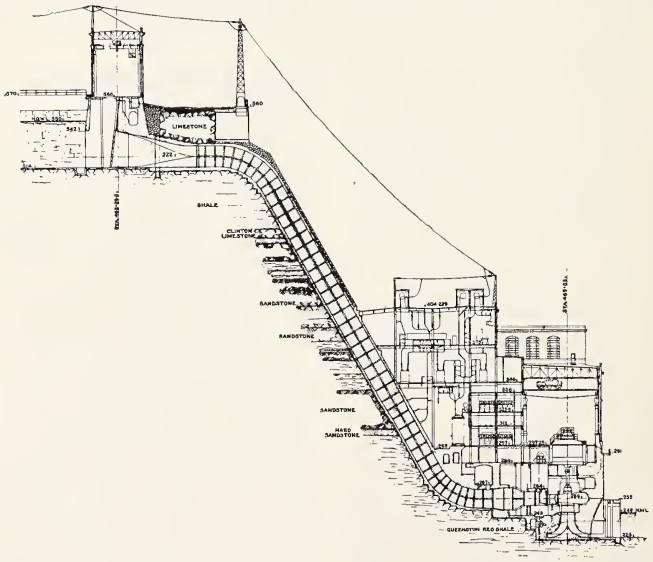
V : 71 THE TRANSMISSION OF ELECTRICITY

Every high-school student knows that electrical energy is readily transformed into heat energy. A current of electricity consists of a shunting of free electrons in the circuit. The energy of these electrons is converted into heat as they encounter opposition to their motion in the conductor. It is apparent that the greater the number of electrons moving and the greater the resistance of the conductor, the greater will be the amount of heat produced. In 1841, James Joule proved experimentally that the heat produced was proportional to the square of the current, to the resistance, and to the time the current flowed ($H \propto I^2Rt$).

It is evident then that the amount of current in a conductor is the most important single factor in heat losses dur-

Ontario Hydro

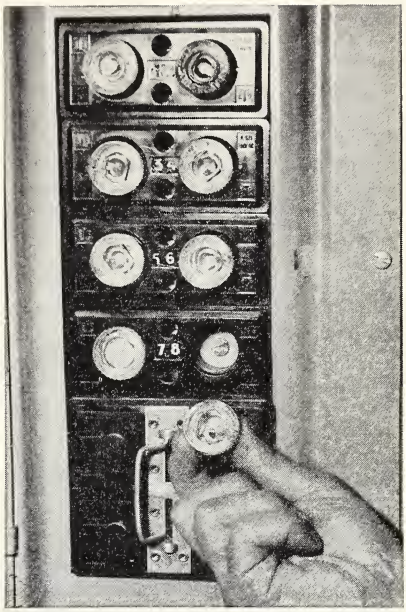
Aerial View of Hydro-Electric Plant, Niagara Falls.



Ontario Hydro

Fig. 29:1 Cross Section of Screen House and Power House.

ing the transmission of electricity. The power of an electric current is equal to the voltage times the current strength, i.e., $P = VI$ (Sec. V:75). This is constant for a given current. Thus, if the voltage is made higher, the current becomes smaller and heat losses will be reduced. For this reason, alternating current produced at a potential difference of 2,200 to 12,000 volts is stepped up to between 50,000 and 220,000 volts for transmission. At the sub-station the voltage is stepped down by transformers so that the pole voltage is usually about 2,200 volts. The familiar pole transformers step this down further to 220 and 110 volts for household circuits. This current is used to operate electric ranges, heaters, lights and various other appliances.



Ontario Hydro

House Fuse Box.

V : 72 FUSES

In designing any electrical circuit care must be taken to ensure that no circuit will carry an overload of current for fear of overheating the conductor. Recall that the heat developed is proportional to the square of the current strength, times the resistance of the conductor. The wiring, then, must be of such a type as to carry the intended current safely. To prevent fires or failure in the circuit through melting of the conductor, fuses are put in as safeguards. In homes, these are usually placed in special boxes near where the current enters.

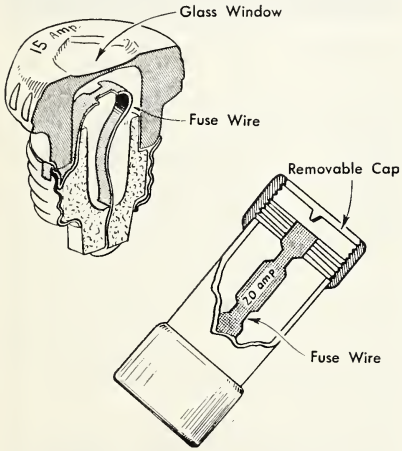


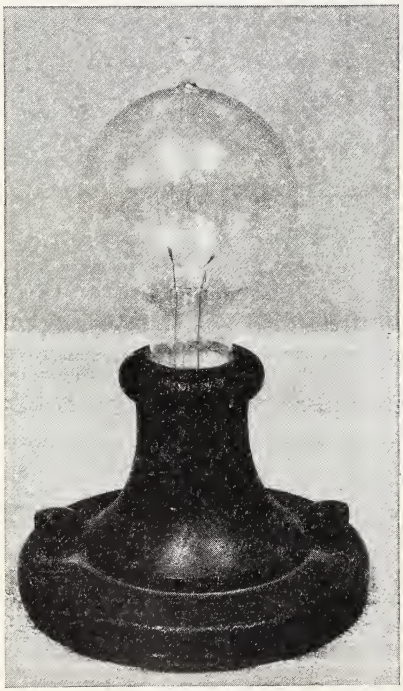
Fig. 29:2 Fuses (a) Plug Type (b) Cartridge Type.

Each fuse consists of a length of metal alloy with a low melting-point enclosed in a case to confine the heat (Fig. 29:2). In the **plug-type fuse** one end is transparent, to permit inspection. In the **cartridge fuse** no opportunity for inspection is provided and larger ones sometimes contain a powder to extin-

guish the arc when the current becomes interrupted by the melting of the metal strip. Each fuse is marked with a number denoting the maximum current in amperes that it is designed to carry. One should be certain that the rating of the fuse is not greater than that of the circuit in which it is used. Any overload should melt the fuse wire instead of harming the rest of the circuit.

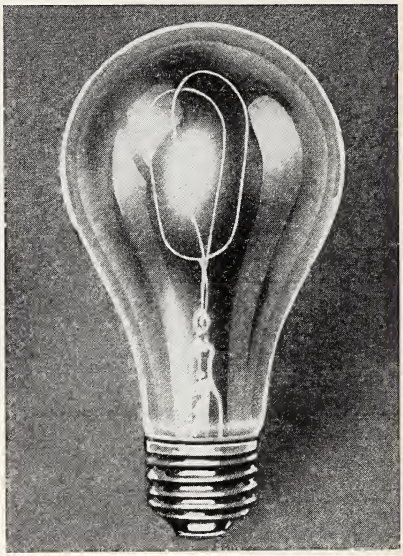
V : 73 THE INCANDESCENT LAMP

In 1879 Thomas Edison exhibited the first incandescent lamp (Fig. 29:3) at his laboratory in New Jersey. The development of this lamp is a story of frustrating research ending in success. In the years preceding 1879 Edison had tried almost every kind of fibre in his efforts to find a filament that would carry the current and emit light. The filament had to have high electrical resistance and a high melting-point; it could not be too brittle even at high temperatures; it had to glow brightly when the current passed through it; finally, it had to be enclosed in an evacuated glass chamber so that it would not burn or unite with oxygen from the air. Eventually, Edison discovered that a carbon filament made by heating bamboo fibres met these conditions and the carbon filament lamp was born (Fig. 29:4).



Thomas A. Edison of Canada Ltd.

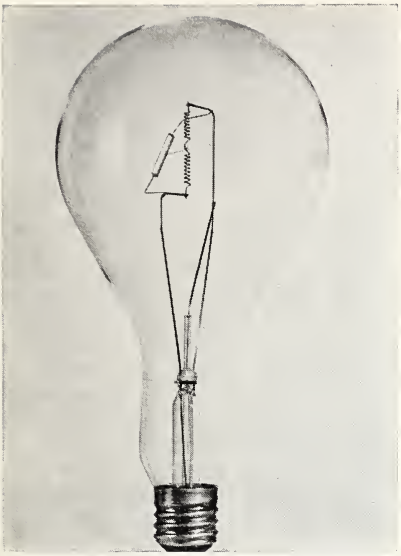
Fig. 29:3 The Incandescent Lamp.



Canadian General Electric

Fig. 29:4 A Carbon Filament Bulb.

Other problems had to be solved before the lamps could be used extensively. Many improvements were found, so that now the modern electric-light



Canadian General Electric

Fig. 29:5 A Modern Tungsten Filament Bulb.

bulb (Fig. 29:5) bears little resemblance to the original. Modern filaments are made of tungsten, giving greater service and whiter light. Instead of evacuated glass bulbs, we now have bulbs filled with an inactive mixture of nitrogen and argon which allows the filament to be heated to higher temperatures. Platinum lead-in wires passing through the glass have been replaced by inexpensive nickel-iron alloys. Costs have gone down while efficiency has been raised to heights not dreamed of a few decades ago.

V:74 OTHER APPLICATIONS OF THE HEATING EFFECT

(a) Domestic Heating Appliances

Nowadays, in many homes, space heaters, hot-water heaters, ranges, etc., use electricity. The appliances designed for these various purposes contain heating-elements usually made of "nichrome" resistance wire. This is an alloy of nickel (80%) and copper (20%) which can be heated to a high temperature without melting, and oxidizing very slowly even when red hot. In addition, it has a resistance of about sixty times that of copper and this reduces the costs.

In electric heaters, the heating-elements are generally supported on fire-clay forms, and in some of the smaller heaters concave polished metal reflectors are used to concentrate the radiant heat into a beam. The electric range has nichrome heating-elements embedded in some suitable insulating material for protection. The elements often consist of two parts. When the switch is set at "high" these are in parallel; when at

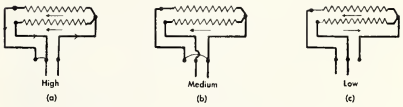


Fig. 29:6 Regulation of Heat in an Electric Stove Element.

"medium" one element is cut out; when at "low" both elements are in series (Fig. 29:6). The walls and door of the oven are filled with heat-insulating material such as fibre glass to reduce the heat loss, the oven temperature being regulated by some form of thermostat.

With electric irons (Fig. 29:7) the heating-elements are usually wound on insulating-sheets of mica situated near the "sole" of the iron. These heating-elements are covered by a layer of asbestos and above this is a heavy iron plate firmly screwed to the base. Electric kettles are also provided with nichrome heating-elements wound on mica and these, sandwiched between mica strips, are firmly held in place below the base of the kettle. In other kettles the heating-element is of the immersion type and consists of a coil of

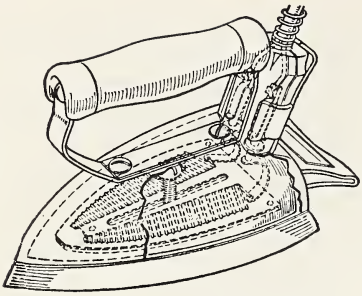


Fig. 29:7 An Electric Iron.

nichrome wire contained in a metal tube from which it is insulated.

(b) The Electric Arc

If two carbon rods are joined across an electric supply of not less than 45 volts, and the ends of the carbons are touched together, an intensely brilliant "arc" of white light appears between the ends of the rods on drawing them slowly apart. This phenomenon was discovered by Davy in 1806, using two thousand simple cells and charcoal rods. These rods were later replaced by gas carbon and the intensity of the light produced by this means led to the extensive use of electric "arc lamps" in street lighting towards the end of the nineteenth century. Arc lights are used as spotlights in theatres.

The heavy current passing on striking the arc produces intense heat between the carbon tips which are thus raised to incandescence. The arc-like flame consists of white-hot particles of carbon torn from one of the rods which thus steadily wears away. If used with a D.C. supply the positive carbon is consumed twice as quickly as the negative rod, and it is found that a "crater" develops at the end of it. Almost all the light originates at this "positive crater," the temperature of which is about 3500°C.

Electric Arc Welding.

Air Reduction Canada Ltd.

(c) The Electric Furnace

Some types of electric furnaces make use of the high temperatures produced by the arc discharge. These arc furnaces are employed in the manufacture of carborundum and calcium carbide—carbon rods being immersed in the constituent chemicals through which an arc-discharge is passed. Another use of the arc furnace is in the "fixation" of atmospheric nitrogen for the preparation of fertilizers.

(d) Electric Welding

The high temperature developed by the electric arc is also applied in electric welding. Boiler plates, ships' plates, etc., can be welded by connecting the plates to the negative of a D.C. supply, applying the positive side to the welding-rod where the weld is to be made.

V : 75 BUYING ELECTRICAL ENERGY

Since electricity is able to do work, it is a form of energy. The faster work is done, the faster energy is utilized. The rate of doing work, i.e., the rate of utilizing energy, is the **power**. Electrical power is measured in watts. **One watt** is the power provided when a current of one ampere flows with a potential difference of one volt. Thus:

$$\text{Power (watts)} = P.D.\,(\text{volts}) \times \text{Current (amps.)}$$

or $P = VI$ watts

$P = (IR)I \; (\because V = IR, \text{Ohm's Law})$

or $P = I^2R$ watts

If the power of one watt is provided for one hour, the consumer must pay for 1 **watt-hour** of energy. Similarly, if one kilowatt (1000 watts) is used for one hour, the consumer must pay for 1 **kilowatt-hour** (k.w.h.) of energy.

Thus electrical energy (k.w.h.)
= power (k.w.) × time (hours).

Note: Since 746 watts = 1 horsepower (h.p.)

it follows that $P = \dfrac{VI}{746}$ h.p.

or $P = \dfrac{I^2R}{746}$ h.p.

Example

Find the cost of operating an electric toaster for two hours if it draws 8 amperes on a 110 volt circuit. The electrical energy costs 4 cents per kilowatt-hour.

$I = 8$ amp. $\quad \because P = VI$

$V = 110$ volts $\quad \therefore P = 110 \times 8 = 880$ watts

$= \dfrac{880}{1000} = .880$ k.w.

$\therefore$ Electric energy used $= .88 \times 2 = 1.76$ k.w.h.

$\because$ 1 k.w.h. costs 4 cents

$\therefore$ 1.76 k.w.h. cost $4 \times 1.76 = 7.04$ cents.

$\therefore$ The cost is 7 cents.

V : 76

QUESTIONS

A

1. (a) Describe what happens to alternating current from the time it is produced at the generator until it is used to operate the electric toaster in your home.
(b) Explain why the voltage is changed before electricity is transmitted across the country.

2. (a) What is the function of a fuse in an electric circuit?
(b) Describe the structure and action of a simple fuse.

3. (a) Make a labelled diagram of an electric-light bulb.
(b) Explain the function of each part labelled in (a).

4. List three appliances found in each of the following, in which the heating effect of electric current is employed, (a) your house (b) your school (c) industry.

5. Define: power, watt, kilowatt, kilowatt-hour.

B

1. At the power-house, electricity at a potential of 12,000 volts is generated. It is prepared for long-distance transmission by being applied to a step-up transformer in which the number of turns of wire in the primary and secondary are in the ratio of 1 to 2000.
(a) What will be the potential difference in the secondary?
(b) How will the current strength be altered?
(c) How will this affect the loss of energy through heating of the conductor during transmission?

2. (a) A pole transformer steps down the line potential from 5500 volts to 110 volts. What is the ratio of the number of turns of wire in the primary and secondary of the transformer?
(b) What change will occur in (i) the current strength (ii) the heating effect?

3. Determine the power of an electric kettle which requires a current of 15 amperes when plugged into a 110 volt electric outlet.

4. What current is drawn by a 550 watt toaster when it is plugged into the 110 volt line?

5. What voltage is applied to a 2970 watt heating-element that draws a current of 13.5 amperes?

6. What is the power (a) in horsepower (b) in watts (c) in kilowatts, of a motor which draws a current of 3.38 amperes on the 110 volt line?

7. What is the maximum power that can be used in a circuit containing a 15 ampere fuse in the 110 volt line?

8. If an electric toaster of 550 watts and an electric kettle of 1000 watts were plugged into the same wall outlet in your home, would the 15 ampere fuse in the circuit melt? Explain your answer.

9. Find the cost of operating an electric toaster for 3 hours if it draws 5 amperes on a 110 volt circuit. The electricity costs 3.5 cents per kilowatt-hour.

10. What is the cost to a storekeeper of leaving a 40 watt light bulb burning near his safe for 36 hours if electricity costs 3 cents per kilowatt-hour?

11. An electric stove element draws 5 amperes on the 220 volt circuit. If it is turned on for 4 hours, what is the cost of operating the stove at 2.2 cents per kilowatt-hour?

12. A ½ h.p. electric motor in an oil furnace comes on for a period of 5 minutes 48 times each day on the average. What is the cost of the electricity for 30 days if it costs 2.5 cents per kilowatt-hour?

13 A boy on returning home from school,

at 4:30 p.m. turns on lights in the kitchen, basement, hall and bedroom. The kitchen has one 100 watt bulb, the basement two 60 watt bulbs, the hall one 40 watt bulb and the bedroom one 40 watt bulb and one 60 watt bulb. If these lights are left burning until 10:00 p.m. what is the cost when electricity costs 3 cents per kilowatt-hour?

CHAPTER 30 ELECTRONICS

V : 77 INTRODUCTION

(a) When a lighted match, or the flame of a gas burner, is brought near the knob of a positively charged electroscope, the leaves will be seen to fall (Chap. 31, Exp. 41). The flame liberates electrons from the atoms of the gases causing them to become positively charged ions. The electrons so set free are attracted to the electroscope and neutralize its charge. Had the charge on the instrument been negative, its charge would have been lost to the positively charged gaseous ions.

(b) An electrical discharge tube with an open side-arm (Fig. 30:1) is attached to the secondary of an induction coil, the discharge points of which are close together. The induction coil is turned on while the tube is being evacuated (Chap. 31, Exp. 42). At first a discharge occurs between the discharge points but, as the tube is partially evacuated, the current ceases between the points and begins between the terminals inside the tube even though they are farther apart. This discharge, though varying in appearance with the degree of evacuation, continues even though the tube is evacuated as completely as possible.

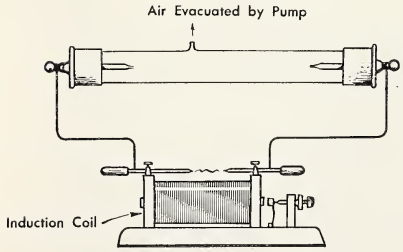


Fig. 30:1 Apparatus to Show Discharge of Electricity at Low Pressures.

The current flows through the gas at reduced pressure because the gas becomes ionized. The electrons expelled from the atoms of gas are attracted to the anode where they re-enter the metallic part of the circuit. The positively charged gaseous ions are attracted to the cathode where they remove electrons from it.

Where the electricity is passing through a vacuum, electrons are expelled from the cathode and proceed in straight lines directly to the anode. The behaviour of electricity as it passes through a gas or a vacuum is known as **electronics.**

The vacuum-tube and the low pressure gas-filled tube have opened the way for a seemingly endless number of new applications of electricity. The most familiar application is the radio, but this is only one of the many being used in our modern way of living. Electronics

is used to guide our ships and aircraft, to perform calculations in minutes that would take a mathematician days, to time delicate processes, to operate radio, television, sound movies, and to perform amazing feats of mechanical control. Its future is likely to be as remarkable as its past—a challenging field for keen young scientists.

V:78 CATHODE RAYS

The main characteristics of the discharge of electricity through gases may be shown by the same method as was used in section V:77(b). At normal pressures the insulating properties of the gas are too great for a spark to occur, but as the pressure is reduced a current is passed and irregular streamers of light traverse the tube between the electrodes each of which is surrounded by a luminous glow. With continued lowering of the pressure the discharge broadens out to a steady luminous column which extends from the anode to almost as far as the cathode. This is known as the positive column and is separated from the cathode glow by a dark space called the Faraday dark space. The pressure in the gas at this stage is about 5 mm. of mercury. Further reduction in the pressure of the gas to about 1 mm. causes the positive column to shrink and to break up into alternate light and dark patches known as striations. The Faraday dark space increases in size at this low pressure, and the cathode glow moves away from the cathode, leaving a dark space between it and the cathode called the Crookes' dark space (Fig. 30:2). When the pressure is about 0.1 mm. the positive column disappears altogether and the negative glow becomes considerably extended. At still lower pressures the negative glow disappears, the Crookes' dark space filling the tube, and the glass walls of the tube, particularly near the anode end, shine with a bright green fluorescent light. The phenomena occurring at this stage of the discharge proved to be most important. If an object is placed some distance in front of the cathode a sharp shadow of the object is cast on the end of the tube near the anode. Experiments suggest

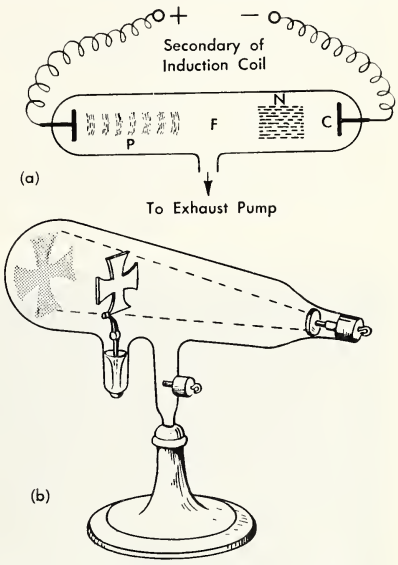


Fig. 30:2 Discharge of Electricity Through Gases. (a) At Reduced Pressures—P, Positive Column; F, Faraday Dark Space; N, Cathode Glow; C, Crookes' Dark Space. (b) At Very Low Pressures—Cathode Rays in Crookes' Tube.

that the fluorescence of the glass is due to something being emitted from the cathode, and Goldstein, in Germany, gave the name of **cathode rays** to this emanation. Crookes, in England, showed that the rays were shot out at right angles from the cathode, caused a rise of temperature of bodies interposed in their path, and that the rays were also capable of producing a mechanical force.

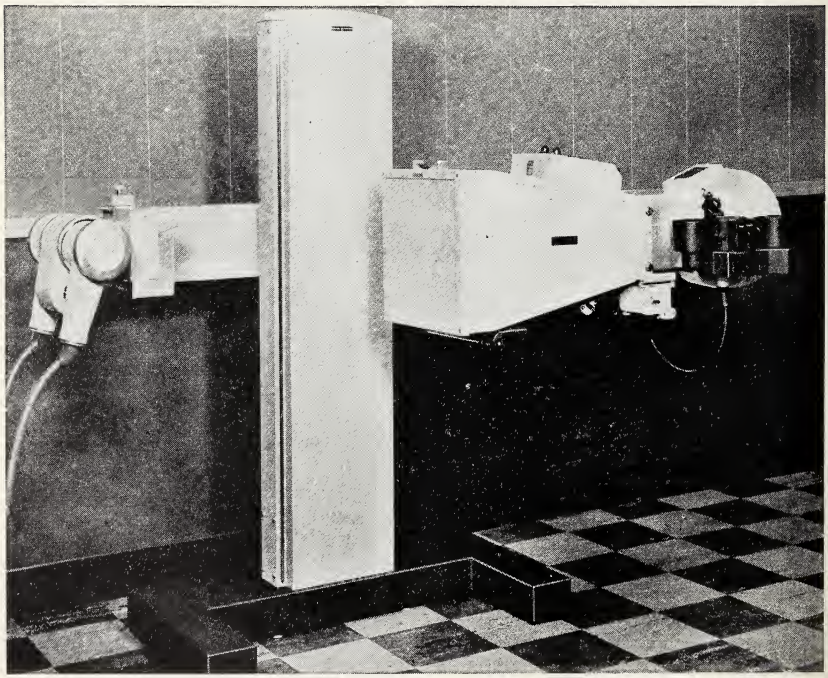
He hazarded a guess that the rays consisted of a stream of particles, and it was later shown that the rays could be deflected by a magnetic field and that they carried a negative charge (Chap. 31, Exp. 43).

It was Sir J. J. Thomson, in England, however, who showed in a series of masterly experiments, carried out at the close of the nineteenth century, that the rays consisted of tiny, identical, negatively electrified particles which we now call electrons. In one of his experiments, in which the rays were deflected by both magnetic and electric fields, he was able to calculate their velocity and also the ratio of the charge to the mass of the particles. The magnitude of the electronic charge had been found by other means, and so he was able to obtain a value for the mass of the electron which he showed to be about 1/1840 part of the mass of the hydrogen atom.

Various forms of the cathode ray tube are in use. One of these, the X-ray tube will be described in the next section. The other, the television picture-tube will be referred to in the next chapter.

V : 79 X-RAYS

While experimenting with discharge tubes at very low pressure, Roentgen, in Germany, in 1895, noted that a fluorescent screen some distance away glowed brightly even when the discharge tube was covered with black paper, and



General Electric

A Chest X-Ray Machine.

objects placed between the tube and screen produced shadows. Roentgen attributed these effects to a new form of radiation emanating from the tube, which, on account of its unknown nature, was called X-rays.

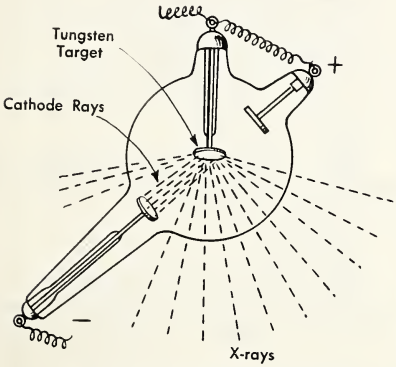


Fig. 30:3 Simple X-Ray Tube.

It is now known that X-rays, or Roentgen rays, are produced whenever cathode rays impinge on a solid object (Chap. 31, Exp. 44). Fig. 30:3 shows a modern form of X-ray tube in which the electrons, constituting the cathode stream, originate from a heated filament (Sec. V:80) and are focused by a concave cathode on to a tungsten or molybdenum target set in a block of copper called the anti-cathode. The face of the anti-cathode is set at an angle of 45° to the axis of the tube, the X-rays coming off in the direction indicated. Most of the energy of the cathode stream is dissipated as heat, only about 1 per cent of the energy is converted into X-rays.

X-rays travel in straight lines, are not deflected by either magnetic or electric fields and produce fluorescence in suitable materials such as platinum-barium cyanide, which is the substance frequently used on X-ray viewing-screens. They affect photographic plates, produce chemical changes, and are capable of discharging electrified bodies since they ionize the air. X-rays are electromagnetic waves of the same nature as visible or ultra-violet rays but having a very much shorter wave-length. One of the most characteristic properties of the rays is their penetrating power. They can pass through many substances opaque to ordinary light waves, the degree of penetration varying inversely as the density of the substance. Roentgen himself noticed this power of penetration and observed that human flesh was more transparent to the rays than bone. The

St. Michael's Hospital

X-Ray Photograph of a Human Hand.

medical uses of X-rays in locating fractures and foreign bodies in the human system are their most important application. Another use of X-rays is the detec-

tion of flaws in metal castings, and research scientists find them a useful aid in many of their investigations.

V : 80 THE ELECTRONIC TUBE

Just as a tap acts as a valve to control the flow of water through the pipes of a house, so the electronic tube acts as a valve to control the flow of electrons in an electric circuit (Chap. 31, Exp. 45, 46). Electronic tubes are able to increase or decrease the amount of current flow, or even to start or stop it, and the action is immediate. They use practically no power in the circuit. No attempt will be made in this text to do any more than to outline the structure and action of the simplest forms of these tubes.

(a) Structure

Any electronic tube has four basic parts (Fig. 30:4):

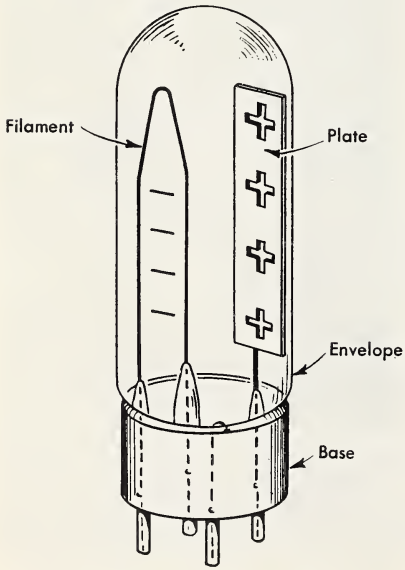


Fig. 30:4 Diode Tube.

1. A glass metal **envelope** enclosing the tube serves to sustain the vacuum or low pressure within the tube;
2. A **cathode**, which is heated either directly by an electric current or indirectly by a heater element which carries the current, serves to give off the electrons when heated;
3. An **anode** serves to receive the electrons from the cathode;
4. A **base** which has four or eight terminals or prongs for connecting the tube into its circuit.

Such a tube is called a **diode.** A **triode** has an additional part called the grid (part d).

(b) Action

When the tube is connected into a circuit, the circuit is actually broken. When the cathode is heated electrons

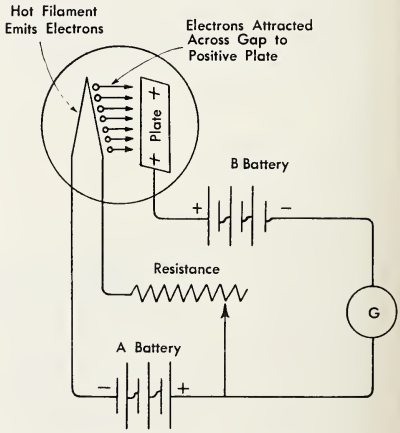


Fig. 30:5 Action of a Diode Tube.

leave its surface. If a positive charge is applied to the anode, these electrons will be attracted across the intervening space and thus a flow of electrons will occur (Fig. 30:5). The anode is frequently referred to as the "plate" and the current

passing through the plate is called the "plate current".

(c) Rectification

If the anode is connected to an alternating-current circuit (Fig. 30:6) it will be alternately positively and negatively charged. While the anode is positive electrons will flow from the cathode to the anode and through the plate circuit. During those half cycles when the anode is negative, the electrons about the

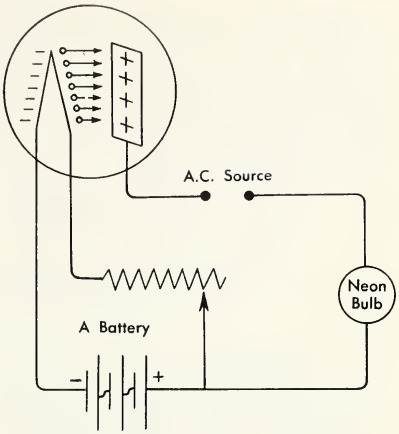


Fig. 30:6 Rectifier Circuit. Electrons are Attracted Only When Plate is Positive.

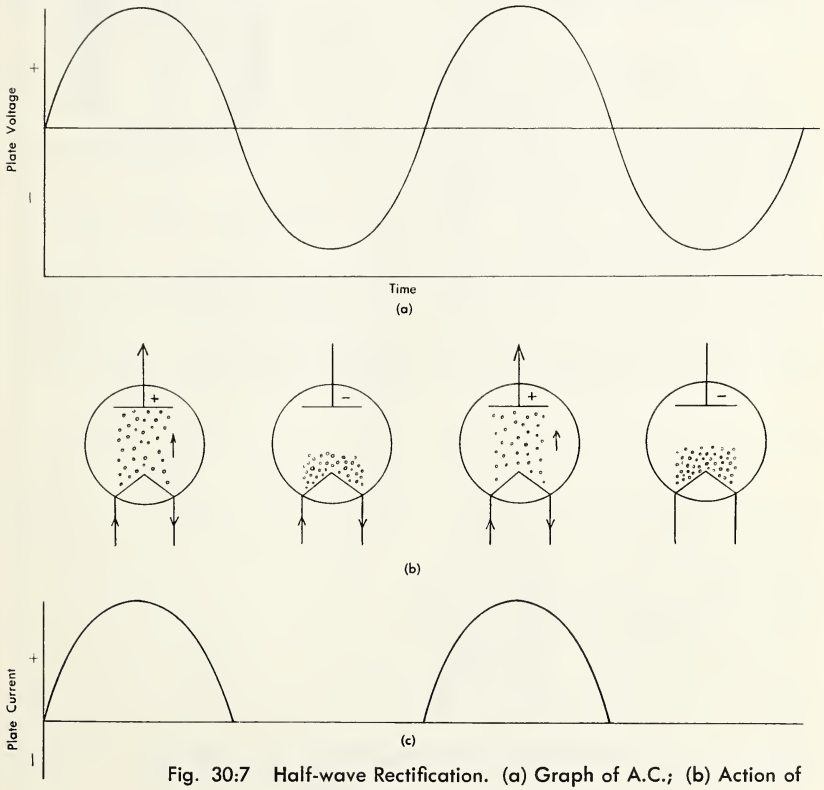


Fig. 30:7 Half-wave Rectification. (a) Graph of A.C.; (b) Action of Rectifier Tube; (c) Graph of Pulsating D.C.

cathode will be repelled and no current will flow. Thus the current passes through the tube in one direction only, from cathode to anode, and a direct current flows in the plate circuit. The tube has been used to obtain direct current from an alternating-current supply. Such a process is called **rectification.** The tube used for the purpose is designated a **rectifier tube.** Half-wave rectification by a diode is illustrated in Fig. 30:7.

(d) Amplification

A triode tube has a fifth part called **the grid** (Fig. 30:8) which controls the current passing through the tube. The grid is a special wire or mesh between the cathode and the anode. Any change in grid voltage causes a proportional change in the amount of current flowing through the tube. Thus, if we have a very weak alternating current, too weak to be used directly, it would be applied to the grid as a signal voltage. As the grid voltage varies it causes an identical amplified variation in the plate current. The grid is given a negative charge just large enough that it never actually becomes positive when the signal is applied.

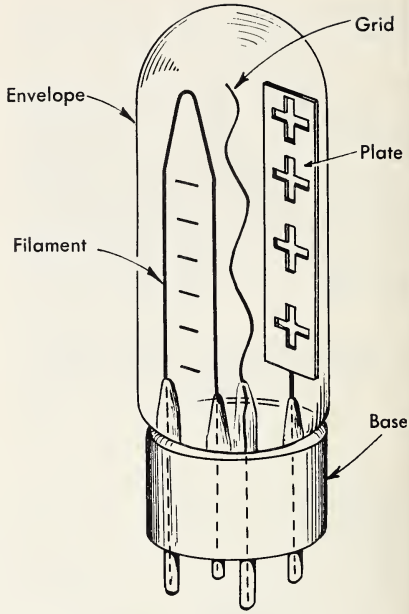


Fig. 30:8 Triode Tube.

Thus, no electrons are attracted to the grid itself so the tube operates at maximum efficiency. Fig. 30:9 illustrates this **amplification** action as a radio signal is impressed on the grid of the triode.

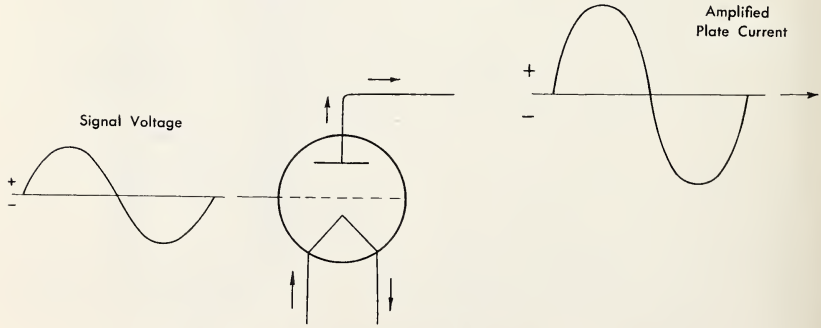


Fig. 30:9 The Function of a Triode Tube as an Amplifier.

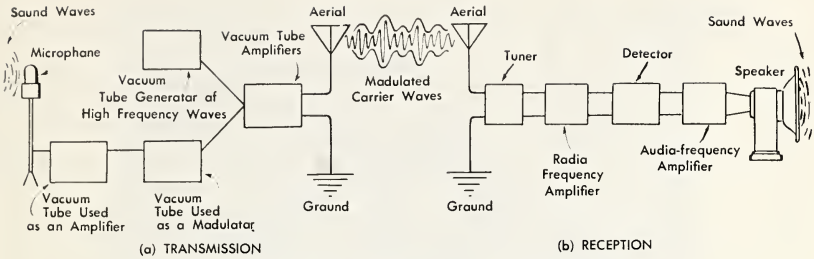


Fig. 30:10 Radio Transmission and Reception.

V : 81 RADIO TRANSMISSION AND RECEPTION

The triode tube can be used as an oscillator which is merely a type of alternating-current generator capable of providing frequencies in the order of 150,000 to 1,500,000 cycles or more per second. As these variations in current are impressed on a transmitting antenna, electromagnetic waves, called carrier waves, are sent out into space. In the transmitting-studio a microphone transforms sound waves into a fluctuating direct current. This current is used to modulate, or cause variations in, the amplitude of the carrier waves from the oscillator.

At the receiving-station the varying electromagnetic waves induce minute potential differences in the antenna. Certain of these, selected by the tuning circuit, are impressed on the grid of an amplifier where they cause correspondingly larger variations in the plate current of the amplifier tube. These currents pass to a detector circuit in which another electronic tube separates the audio frequency component of the wave (i.e., the part that can be converted to audible sound) from the radio frequency of the carrier wave. These audio frequency components are further amplified and used to operate the diaphragm of earphones or a magnetic speaker. A simple diagram illustrating the above principles is shown in Fig. 30:10. Students desiring further information on the principles and structure of radio circuits are referred to the *Radio Amateurs' Handbook* or specialized texts on radio.

V : 82 PHOTOELECTRICITY

Photoelectric cells or, as they are commonly called, "electric eyes", are the result of almost one hundred years of careful investigation. In 1888, Hallwacks, a German scientist, found that negatively charged zinc plates lost their charges when exposed to ultra-violet light coming from an arc-lamp (Fig. 30:11). Thus electrons were shown to be released from certain substances when light falls upon them. This effect may be demonstrated visually if a zinc plate is attached to an electroscope (Chap. 31, Exp. 47). This is called **photo-emission** of electrons.

A short time later it was discovered that the alkali metals, sodium, potassium and caesium are sensitive even to ordinary visible light. Modern emissive type photoelectric cells use these metals and are similar in appearance to radio vacuum-tubes. A layer of light-sensitive metal coats the entire inner surface of the tube with the exception of one small area which admits light. A positively charged anode is located in the centre of the tube and serves to attract elec-

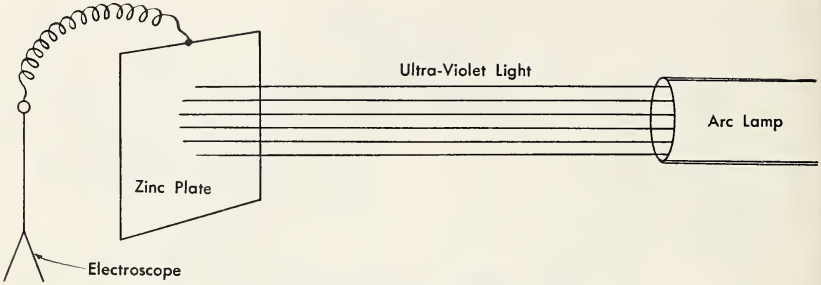


Fig. 30:11 Zinc Plate Loses Electrons When Exposed to Rays from an Arc-Lamp.

trons from all sides as they are released (Fig. 30:12). The rate of electron emission is proportional to the amount and nature of the light falling upon the metal. Such cells control circuits which are used to open and close store doors, operate

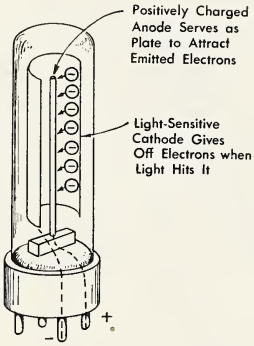


Fig. 30:12 Photoelectric Cell.

burglar alarms, control dangerous machinery, reproduce sound for movies, count articles on production lines, and for hundreds of other purposes contributing to the efficiency and safety of industrial processes (Fig. 30:13).

The **photronic cell** is used almost universally to-day for all the above processes with the exception of sound reproduction. It consists of a metal supporting disc upon which is deposited a layer of light-sensitive material. Over this is placed a transparent metal grid which acts as an electrode and collector for the electrons set free by light. Students

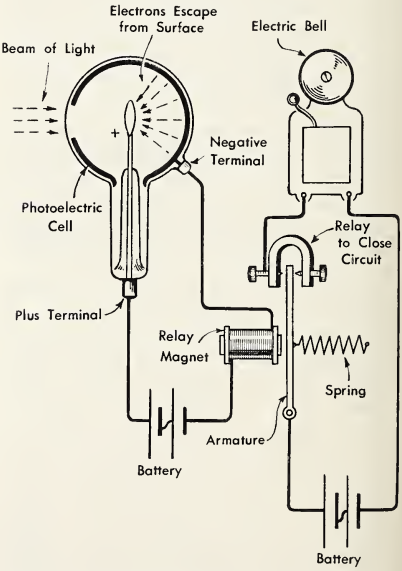


Fig. 30:13 Photoelectric Cell Used to Operate an Electric Bell.

Canadian General Electric

The Component Parts of a Light-Meter.

interested in photography will recognize the light-meter as a simple application of the photronic cell.

In these devices light energy is converted into electrical energy. This, in part, provides the answer to the scientists' dream of eventually tapping the huge resources of the sun itself.

V : 83 QUESTIONS

1. (a) What is the meaning of the term electronics?
   (b) State two facts fundamental to electronics.
   (c) Distinguish between thermionic emission and photo-emission of electrons.
2. (a) What are cathode rays?
   (d) Describe some properties of cathode rays.
   (c) How are cathode rays produced?
3. (a) Explain how X-rays are produced.
   (b) Describe some properties of X-rays.
   (c) How are these properties associated with the uses of X-rays?
4. (a) Make a labelled diagram of a simple diode tube. State the purpose of each part.
   (b) How does a triode tube differ from a diode tube?
5. (a) What is meant by rectification?
   (b) Explain why a diode tube may be used as a rectifier.
6. (a) What is meant by amplification?
   (b) Explain why a triode tube may be used as an amplifier.
7. Describe briefly how radio signals are sent from one station to another.
8. (a) Describe the structure of (i) a simple photoelectric cell (ii) a photronic cell.
   (b) What transformation of energy takes place in each of the above cells?

CHAPTER 31 EXPERIMENTS ON MAGNETISM AND ELECTRICITY

EXPERIMENT 1

To distinguish between magnetic and non-magnetic substances. (Ref. Sec. V:2)

Apparatus

Bar magnet, assortment of small articles made from iron, paper, glass, wood, copper, nickel, rubber, tin, silver, plastic, etc.

Method

Approach each of the articles in turn with the bar magnet. Tabulate your results.

Observations

State which objects were attracted and which were not attracted by the magnet.

Conclusions

1. State which were magnetic substances and which were non-magnetic substances.
2. Define (a) magnetic substances, (b) non-magnetic substances.

EXPERIMENT 2

To determine if the magnetic strength is equal in all parts of the bar magnet. (Ref. Sec. V:2)

Apparatus

Bar magnet, iron-filings.

Method

Sprinkle iron-filings liberally on a piece of paper. Roll the bar magnet in the filings and observe. Clean the magnet carefully with a cloth at the end of the experiment and return the filings to their container.

Observations

1. Are the filings attracted equally to all parts of the bar magnet?
2. Where do most of the filings collect?

3. Where does the least number of filings collect?
4. Compare the number of filings collected at each end of the magnet.

Conclusions

1. Where is the magnetic strength of a bar magnet concentrated? What are the these areas called?
2. Where is the least magnetic strength in a bar magnet?

EXPERIMENT 3

To determine the difference between the poles of a bar magnet. (Ref. Sec. V:2)

Apparatus

Bar magnet, chalk, non-magnetic stand, brass support.

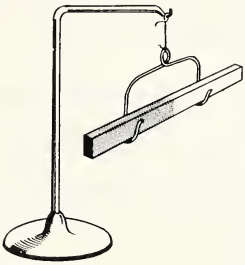


Fig. 31:1

Method

1. Mark one end of the magnet with chalk so that it may be readily identified.
2. Suspend the magnet horizontally from the non-magnetic stand by means of thread supporting a brass support.
3. Allow the magnet to swing freely until it comes to rest. Note the direction in which the marked end is pointing.
4. Reverse the ends of the magnet in the support and again let it swing freely until it comes to rest.

Observations

1. In what direction did the marked end of the magnet point when it came to rest the first time?
2. In what direction did the marked end of the magnet point when it came to rest the second time?

Conclusions

1. Along what directional line will a freely suspended bar magnet always come to rest?

2. Why do we call one end of a bar magnet the north-seeking pole and the other end the south-seeking pole? What abbreviations for these are in common use?

EXPERIMENT 4

To investigate the effect of bringing like and unlike magnetic poles together. (REF. SEC. V:2)

Apparatus

Two bar magnets of known polarity, non-magnetic stand, brass support (Fig. 22:3).

Method

1. Suspend one bar magnet from the non-magnetic stand by a thread and a brass support so that it is free to move in a horizontal plane, or balance a bar magnet horizontally on the convex surface of a watch glass.
2. Approach the N-pole of the suspended magnet with the N-pole of the other magnet.
3. Repeat, using the N-pole of the suspended magnet with the S-pole of of the other.
4. Now approach the S-pole of the suspended magnet with each end of the other.
5. Tabulate your results.

Observations

POLE OF SUSPENDED MAGNET	POLE OF OTHER MAGNET	OBSERVATION
N-pole	N-pole	
N-pole	S-pole	
S-pole	N-pole	
S-pole	S-pole	

Conclusions

1. What is the effect of like magnetic poles on each other?
2. How do unlike magnetic poles affect each other?
3. The above two conclusions combined into one statement give us the **Law of Magnetism.** State this important law.

Questions

1. If the polarity of the magnets to be used is not known, how could you determine this information?
2. Why is it correct to say that the north magnetic pole of the earth contains S-pole magnetism?

EXPERIMENT 5

To study the magnetic field about a bar magnet.
(REF. SEC. V:4)

Apparatus

Two bar magnets, iron-filings, sheet of paper.

Method

1. Lay a bar magnet on the desk and place a book of approximately the same thickness as the magnet on either side of it. Place the paper over the magnet so that the edges of the paper are supported by the books (a magnet board may be used to support the magnet and paper instead of the books). Sprinkle iron-filings evenly over the surface of the paper while tapping it gently.
2. Repeat the above procedure using the two bar magnets placed with their N-poles about 2 in. apart.
3. Repeat part 2 with an N-pole and an S-pole about 2 in. apart.

Observations

1. Where are the lines of filings most concentrated?
2. Where are the lines least concentrated?
3. What is the general shape of the lines formed?
4. Do any of the lines appear to cross each other?
5. Where do the lines seem to begin and end in the case of the single bar magnet?
6. Describe the lines formed when like poles are adjacent to each other.
7. Describe the lines formed when unlike poles are adjacent to each other.

Conclusions

1. What causes the iron-filings to take up their positions about the bar magnet?
2. What evidence have you found that supports the theory that lines of force repel each other?
3. What property of lines of force explains the attraction of unlike poles?
4. What evidence have you found that would indicate that the field is strongest close to the poles of the magnet?

Questions

1. Make a diagram of each of the patterns formed by:
   (a) A single bar magnet.
   (b) Two bar magnets with like poles adjacent.
   (c) Two bar magnets with unlike poles adjacent.
2. Indicate by means of a diagram what you would expect the field of force about a horseshoe magnet to look like. Verify your prediction by experiment.

EXPERIMENT 6

To study induced magnetism. (REF. SEC. V:6)

Apparatus

Bar magnet, long iron nail, iron tacks, magnetic compass.

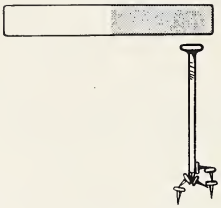


Fig. 31:2

Method

1. Place one end of the nail near the tacks to test for magnetic power. Now hold one end of the bar magnet near one end of the nail. Allow the other end of the nail to come in contact with the tacks. Lift the magnet and the nail together. Then move the magnet away from the nail.
2. With the head of the nail near the N-pole of the magnet, approach the N-pole of the compass-needle with the point of the nail. Repeat this with the head of the nail near the S-pole of the magnet.

Observations

1. Did the nail by itself possess magnetic powers?
2. When a pole of the magnet was close to the nail, what was the effect on the tacks?
3. What occurred when the magnet was moved away from the nail?
4. With the N-pole of the magnet near the head of the nail, how was the N-pole of the compass-needle affected?
5. What occurred when the S-pole of the magnet was used?

Conclusions

1. Why did the nail act as a magnet when under the influence of the bar magnet?
2. Why did it not remain a magnet when the bar magnet was removed?
3. What polarity was induced in the end of the nail (a) nearer to (b) farther from the pole of the magnet used?

Questions

1. Why do we specify an iron nail and iron tacks?
2. Why should a long nail be used?

EXPERIMENT 7

To determine if the earth's magnetic field can cause induced magnetism. (Ref. Sec. V:6)

Apparatus

Dipping-needle (Fig. 22:8), soft iron bar about 12 in. long, hammer, magnetic compass.

Method

1. Determine the direction of the magnetic lines of force at your location on the earth's surface by means of the dipping-needle (Sec. V:5).
2. Test the iron bar for magnetic polarity by approaching the N-pole of the compass-needle with each end in turn.
3. Holding the iron bar at the angle indicated by the dipping-needle, strike the bar sharply several times with the hammer.
4. Again test the bar for magnetic polarity using the magnetic compass.

Observations

1. What is the magnitude of the angle of inclination?
2. What was the result of testing each end of the iron bar with the compass in the first case?
3. After striking the bar what changes were observed when it was tested with the compass?

Conclusions

1. Why was the test different in the second case than in the first?
2. From your observations what magnetic polarity must the north magnetic pole of the earth possess?

EXPERIMENT 8

To study magnetic shielding. (Ref. Sec. V:6)

Apparatus

Demonstration magnetic compass-needle, bar magnet, thin sheets of iron, glass, copper, wood.

Method

1. Hold the bar magnet to one side of the compass-needle so that it will be attracted towards the magnet.
2. Move the point of the compass-needle to one side and release it, allowing it to begin swinging from side to side. Note the number of vibrations in 10 seconds and the time in which it finally comes to rest.
3. Insert the iron sheet between the compass-needle and the magnet and repeat the above procedures, taking care that all other conditions remain the same as before.
4. Repeat part 3 using other materials.

Observations

1. Number of v.p.s. without shield
2. Time to come to full stop without shield
3. Number of v.p.s. with iron shield
4. Time to come to full stop with iron shield.
5. Repeat the above observations when other materials are inserted.

Conclusions

What is magnetic shielding?

Questions

1. Why is it necessary to shield a magnetic compass on board a ship?
2. How can such magnetic shielding be accomplished?

EXPERIMENT 9

To magnetize a steel wire. (REF. SEC. V:7)

Apparatus

Bar magnet, steel wire or thin knitting-needle, magnetic compass.

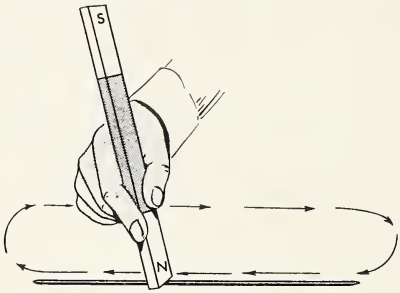


Fig. 31:3

Method

1. Test the ends of the wire for magnetism, using the compass.
2. Using the N-pole of the bar magnet stroke the wire from one end to the other several times, always in the same direction. Lift the magnet well away from the wire as you return it to the starting point for each stroke. Test each end of the wire for polarity, using the compass.
3. Repeat the above steps using the S-pole of the bar magnet to stroke the wire.

Observations

State observations for each part described above.

Conclusions

1. What indication did you have that the wire was not magnetized before it was stroked with the magnet?
2. What makes you believe that the wire has become a bar magnet during the experiment?
3. What was the polarity of the end of the wire last touched by the pole of the bar magnet?

Questions

1. Why were both ends of the wire tested for magnetic polarity?
2. Why was the bar magnet lifted away from the wire as it was returned at the end of each stroke?
3. Explain why the wire became magnetized.

EXPERIMENT 10

To investigate some experimental evidence for the theory of magnetism. (Ref. Sec. V:7)

Apparatus

A magnetized steel wire, wire cutters, magnetic compass.

Method

1. Determine the polarity of the steel wire.
2. Cut the wire in half and determine the polarity of each half.
3. Cut the pieces into smaller and smaller sections and determine the polarity of each piece.

Observations

By means of diagrams illustrate your observations.

Conclusion

From these observations what inference can be made about the basic structure of a magnet?

EXPERIMENT 11

To investigate further experimental evidence for the theory of magnetism. (Ref. Sec. V:7)

Apparatus

Test-tube, iron-filings, stopper, bar magnet, magnetic compass.

Method

1. Fill the test-tube with iron-filings and insert the stopper. Test the tube for magnetic polarity.
2. Stroke the test-tube from end to end several times using one pole of the bar magnet as was done in experiment 9. Test the tube again for magnetic polarity.
3. Shake the test-tube vigorously and again test it for polarity.

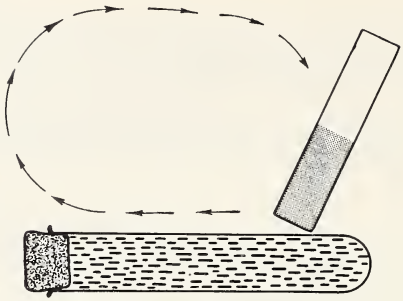


Fig. 31:4

Observations

1. Did the tube of filings act as a magnet when first tested?
2. Was any movement of the filings noticed as the test-tube was stroked?
3. What was observed in the second polarity test?
4. How did the shaking affect the magnetic properties?

Conclusion

How does this experiment support the theory of magnetism?

Question

Would there be any limit to the magnetic strength produced? Explain.

EXPERIMENT 12

To produce static electricity by friction. (REF. SEC. V:10)

Apparatus

Hard rubber or ebonite rod, glass rod, cat's fur, piece of silk, small scraps of papers, sawdust and other light objects.

Method

1. Rub the ebonite rod with the cat's fur. Bring the rod near the objects.
2. Repeat the above procedure, rubbing the glass rod with the silk.

Note Lucite rubbed with a sheet of rubber or polystyrene (the material used in transparent vegetable containers) is an excellent substitute for glass and silk.

Observations

Describe the behaviour of the objects as the rod approaches in each case.

Conclusion

What is the effect of rubbing an ebonite rod with cat's fur or a glass rod with silk?

Questions

1. What transformation of energy is involved in producing static electricity by friction?
2. What evidence is there that this new power of attraction is not magnetism?
3. Describe instances in your everyday life in which you have encountered static electricity.

EXPERIMENT 13

To show that there are different kinds of electrical charges and to establish the law of electrical charges. (Ref. Sec. V:11)

Apparatus

Two ebonite rods, two glass rods, insulated stand, thread, stirrup, cat's fur, silk.

Method

1. Charge an ebonite rod by rubbing it with cat's fur. Suspend the charged rod in the stirrup attached by a thread to the insulated stand. Approach the charged end of the ebonite rod with the other charged ebonite rod.
2. Approach the charged end of the ebonite rod with the charged end of a glass rod which has been rubbed with silk.
3. Replace the suspended ebonite rod by a charged glass rod and repeat the procedures outlined above.

Observations

What is observed in each of the above parts?

Conclusions

1. Are there different kinds of electrical charges? Name each kind.
2. What simple law of electrical charges may now be stated?

Question

What standard method have we of producing each kind of charge in the laboratory?

EXPERIMENT 14

To study the use of the pith-ball electroscope. (Ref. Sec. V:13)

Apparatus

Pith-ball electroscope, ebonite rod, cat's fur, glass rod, silk.

Method

1. Charge the ebonite rod and slowly bring it near the pith balls. Allow them to touch the rod, and observe.

2. After charging the pith balls approach them slowly with (a) a negatively charged rod and (b) a positively charged rod.
3. Repeat the above procedures using a charged glass rod in part 1.

Observations

Describe what is observed in each part above.

Conclusions

1. Explain each observation.
2. How may the pith-ball electroscope be used to (a) detect (b) identify an electrical charge?

Questions

1. What is meant by "charging by contact"? Explain this process.
2. Why is repulsion the only sure evidence that an object is charged?

EXPERIMENT 15

To study the use of the gold-leaf electroscope. (REF. SEC. V:13)

Apparatus

Gold-leaf electroscope, ebonite rod, cat's fur, glass rod, silk, stick of sealing-wax, piece of flannel.

Method

1. Charge the ebonite rod and slowly bring it near the knob of the electroscope until it touches. Withdraw the charged ebonite rod.
2. Approach but do not touch the knob of the charged electroscope with (a) another negatively charged rod (b) a positively charged glass rod (c) a stick of sealing-wax that has been rubbed with flannel.
3. Remove the charge from the electroscope by touching the knob with a finger.
4. Repeat parts 1 and 2, touching the knob with a charged glass rod.

Observations

Describe the observations for each part above.

Conclusions

1. What charge is given to the electroscope when it is "charged by contact" with (a) a positively (b) a negatively charged rod?
2. What procedure can be used to identify an unknown charge on an object?

EXPERIMENT 16

To distinguish between conductors and insulators.
(REF. SEC. V:14)

Apparatus

Gold-leaf electroscope, ebonite rod, cat's fur, various objects in the room.

Method

1. Place a negative charge on the electroscope by touching the knob with the charged ebonite rod.
2. Approach the knob of the charged electroscope with the charged ebonite rod. Note what happens.
3. Rub the charged rod on a water pipe and again approach the knob. Note what happens.
4. Recharge the rod after each test and repeat step 3, rubbing the charged rod on rubber, slate, wood, your hand, and dipping it in water.

Observations

Note the effect on the electroscope leaves in each case.

Conclusions

1. List those materials which allowed the charge to escape. What are such materials called?
2. List those that did not permit the charge to escape. What are they called?

EXPERIMENT 17

To produce induced electrical charges. (Ref. Sec. V:15)

Apparatus

Two metal spheres on insulated stands, proof-plane, ebonite rod, cat's fur, glass rod, silk, gold-leaf electroscope.

Method

1. Charge the electroscope negatively by the contact method.
2. Test each sphere for the presence of a charge by bringing it near the knob of the charged electroscope.
3. Place the two spheres *A* and *B* in contact as shown in Fig. 23:6. Approach, but do not touch, sphere *A* with the end of a negatively charged ebonite rod. Remove *B* from *A* and then remove the rod. Again test each sphere as in part 2.
4. Touch the spheres to each other and test each for a charge as in part 2.
5. Repeat parts 3 and 4, using a positively charged rod.

Observations

State what was observed.

Explanation

Explain your observations in this experiment with reference to the electron theory.

Conclusions

1. In each case what charge was induced on (a) the sphere near the inducing charge (sphere A), (b) the sphere distant from the inducing charge (sphere B)?
2. What do you conclude about the magnitude of these two induced charges?

EXPERIMENT 18

To charge a gold-leaf electroscope by induction. (REF. SEC. V:16)

Apparatus

Gold-leaf electroscope, ebonite rod, cat's fur, glass rod, silk.

Method

1. Charge an ebonite rod negatively and approach, but do not touch, the knob of the electroscope with it. Keeping the charged rod near, touch the knob with a finger, i.e., "ground" the knob. Remove your finger. Then remove the charged rod.
2. Repeat the procedure, using a positively charged glass rod.

Observations

Record the behaviour of the leaves in each step of the method by means of a series of diagrams.

Explanation

Using the electron theory, indicate on the diagrams what occurred in each of the above steps.

Conclusions

What charge can be induced on the electroscope with (a) a negatively charged rod, (b) a positively charged rod?

Question

Describe how to charge an electrophorus (Sec. V:17) by induction. Explain fully.

EXPERIMENT 19

To investigate the distribution of electric charges on a charged object. (SEC. V:19)

Apparatus

Electrophorus, proof-plane, gold-leaf electroscope, Biot's spheres (Fig. 23:11), several insulated conductors of different shapes.

Method

A. Using Biot's Spheres

1. Charge the disc of the electrophorus and transfer the charge by contact to the insulated metal sphere.

2. Test the insulated metal hemispheres for electric charge by means of a proof-plane and the electroscope.
3. Then place the hemispheres tightly around the charged sphere. Remove the hemispheres and using the proof-plane and electroscope again test them for charge.
4. Test the sphere for the presence of electric charge.

Observations

Describe clearly what occurred in the above steps. Explain fully.

Conclusion

Where do electric charges reside on a charged object?

B. Using Conductors of Different Shapes

1. Using the disc of the electrophorus, charge the conductors by contact.
2. Touch various parts of each conductor with the proof-plane and bring it to a given distance from a charged electroscope each time. Note the amount of deflection in each case and compare the density of charge on the various parts of each conductor.

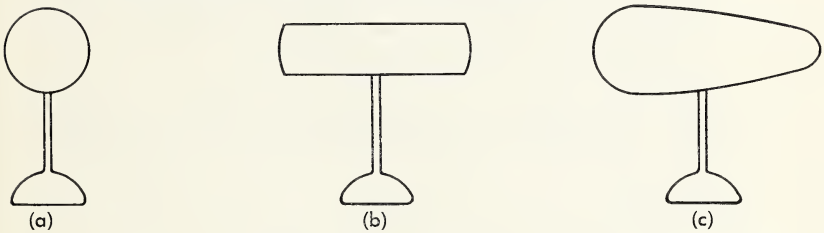


Fig. 31:5

Observations

Describe clearly what occurred.

Conclusion

Where is there the greatest density of charge on the surface of an irregularly-shaped object?

EXPERIMENT 20

To study the action of pointed conductors. (Ref. Sec. V:20)

Apparatus

Wimshurst machine, metal point, candle.

Method

Attach the metal point to one terminal of the Wimshurst machine. Turn the handle rapidly to generate an electric charge. Hold the lighted candle in front of the point when it has become highly charged.

Observation

What happens to the flame of the candle?

Explanation

What causes this phenomenon?

Conclusion

What effect do points have on the charge residing on a conductor?

Application

Explain the action of lightning-rods.

EXPERIMENT 21

To study the action of a voltaic cell. (REF. SEC. V:23, 24)

Apparatus

Glass vessel, strips of copper and zinc metal, flash-light bulb, socket, water, potassium dichromate.

Method

1. Slowly add 10 ml. of concentrated sulphuric acid to 200 ml. of water, with continuous stirring. Pour this solution (the electrolyte) into the glass vessel. Immerse the two plates in the electrolyte parallel to each other but not touching. Note what occurs.
2. Connect the plates by wires joined to the flash-light bulb. Note what happens at both plates and to the flash-light bulb.
3. Add ¼ teaspoonful of potassium dichromate and stir until it dissolves.

Observations

1. Is there any change noted at both plates in part 1?
2. (a) What changes occur at the plates in part 2?
   (b) What happens to the light bulb in part 2?
3. What is the result of adding potassium dichromate?
4. What eventually happens to the electrodes as the action continues?

Explanations

1. What is the cause of the changes at the zinc plate?
2. What must have been produced to make the light bulb glow?
3. Account for the change in the glowing that is observed.
4. What is the action of the potassium dichromate?
5. Why will the action of the cell eventually stop?

Conclusions

1. How is electric current produced in a voltaic cell?
2. What is (a) local action (b) polarization? How may they be prevented?

Questions

Why is the voltaic cell as used in this experiment not in common use to-day?

2. What name, describing its action, can be given to the potassium dichromate in this experiment?

EXPERIMENT 22

To determine the relationship between potential difference (V), current strength (I), and resistance (R) of an electric circuit (Ohm's Law). (Ref. Sec. V:33)

Apparatus

Resistance coil*, a number of dry cells, galvanometer (Sec. V:53), knife switch.

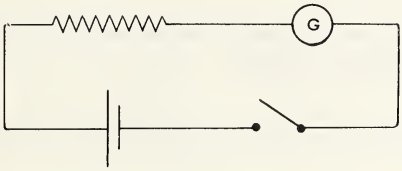


Fig. 31:6

Method

1. Connect one dry cell, the resistance coil, the galvanometer, and the knife switch in a series circuit as indicated in the diagram.
   Close the switch and note the deflection of the galvanometer. Open the switch.
2. Repeat the above procedure using two, three, four and then five dry cells in series. Record all your results in the table below.

Observations

Number of Cells	Galvanometer Deflection (Divisions)	No. of Cells ÷ Galvanometer Deflection
1		
2		
3		
4		
5		

Explanations

1. What is represented by number of cells? How could it be represented using an electrical symbol?
2. What is represented by the galvanometer deflection? How could it be represented using an electrical symbol?
3. How do the ratios obtained by dividing the number of cells by the

*The instructor should ensure that the resistance used is of a correct value to give good results with the galvanometer and potentials employed.

galvanometer deflections compare? This ratio is called the resistance R.

Conclusions

1. State Ohm's Law.
2. Express it, using symbols.

Questions

1. Name the units used for measuring potential difference, current strength, and resistance.
2. Define "ohm".

EXPERIMENT 23

To determine the resistance of an unknown resistance by the voltmeter-ammeter method. (REF. SEC. V:38)

Apparatus

Voltmeter, ammeter, rheostat, dry cells, unknown resistance.

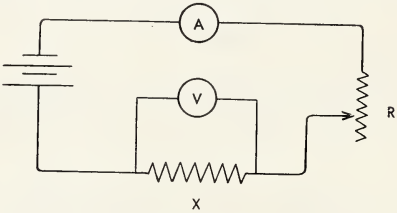


Fig. 31:7

Method

1. Connect the voltmeter, ammeter, rheostat and dry cells in a circuit with the unknown resistance X as shown in the diagram.
2. Adjust the rheostat, R, until any suitable value of current flows.
3. Determine the value of the current in amperes by reading the ammeter. Determine the potential difference in volts by reading the voltmeter.
4. Calculate the value of X in ohms.

Observations

$V =$
$I =$

Calculations

Determine the value of X using Ohm's Law.

Conclusion

What is the value of the unknown resistance?

Questions

1. Why may the setting of the rheostat be varied without affecting the final result?
2. Why is the rheostat used in this circuit?
3. Why is the voltmeter connected in parallel with the unknown resistance?

EXPERIMENT 24

To determine the resistance of an unknown resistance by the substitution method. (Ref. Sec. V:38)

Apparatus

Ammeter, resistance box, rheostat, dry cell, unknown resistance.

Method

1. Connect the ammeter, rheostat and dry cell in series with the unknown resistance. Adjust the rheostat to get a large deflection of the ammeter.
2. Remove the unknown resistance and substitute the resistance box with all plugs removed. Replace the plugs singly and in groups of two or more until you get the same ammeter reading as before.

Observation

What is the total resistance indicated by the unreplaced plugs?

Conclusion

What is the value of the unknown resistance?

EXPERIMENT 25

To study electrolysis of water. (Ref. Sec. V:41)

Apparatus

Simple electrolytic cell, pair of platinum electrodes, electrolyte consisting of one part sulphuric acid slowly added to approximately ten parts of water with constant stirring, source of direct current, test-tubes, wood splints.

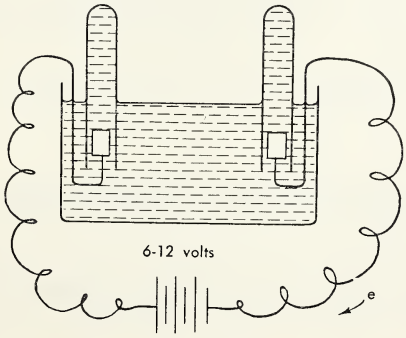


Fig. 31:8

Method

1. Fill the electrolytic cell almost to the top with electrolyte. Completely fill the two test-tubes with the same liquid and invert one over each electrode as shown in the diagram. Connect the electrodes to the current source noting which is the cathode (—), and which is the anode (+).
2. Allow the current to flow until one test-tube is almost filled with gas. Measure and compare the lengths of the gas column in the two test-tubes.
3. Remove the test-tubes and immediately lower a burning splint into each in turn. Note the results.

Observations

1. What is observed at the anode and at the cathode as the current flows?
2. Compare the volume of gas produced at the anode with that at the cathode in a given time.
3. What was observed when the splint was lowered into each of the gases in part 3?

Conclusions

1. What gas is produced at (a) the anode (b) the cathode?
2. What are the relative volumes of the two gases?
3. Define cathode, anode, electrolyte, electrolysis.

Explanation

Write a brief explanation of electrolysis of water (Sec. V:41). Include in your explanation a description of what the current consists of in (a) the external circuit (b) the electrolyte.

Questions

1. Why was sulphuric acid added to the water in making the electrolyte?
2. Why were the electrodes made of platinum?
3. What would be the effect on the quantities of gases produced of (a) increasing the current strength, (b) increasing the length of time that it flows.

The Hoffman water voltameter (Fig. 26:2) may be used in place of the above apparatus.

EXPERIMENT 26

To study electrolysis of copper sulphate solution.
(REF. SEC. V:42)

Apparatus

Electrolytic cell, pair of carbon electrodes, solution of copper sulphate, source of direct current, test-tube, wood splints.

Method

1. Fill the electrolytic cell almost to the top with the copper sulphate solution. Connect the electrodes to the current source. Allow the current to flow for several minutes. Note what occurs at both electrodes. Note any change in the colour of the electrolyte.
2. Collect a test-tube full of the gas liberated at the anode as described in the previous experiment and test it with a glowing splint. Also, examine the deposit at the cathode.

Observations

Describe all observations.

Conclusion

What is obtained at (a) the anode (b) the cathode?

Explanation

Write a brief explanation of the electrolysis of copper sulphate solution.

EXPERIMENT 27

To discover the factors that affect the amounts of materials liberated at the electrodes during electrolysis.
(Ref. Sec. V:43)

Apparatus

As in experiment 25, with ammeter and rheostat in series with the electrodes.

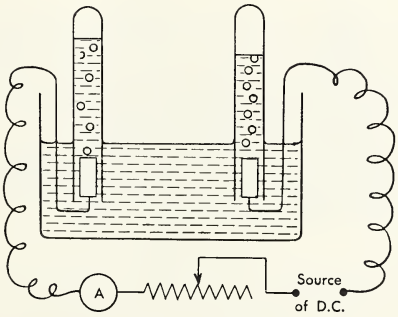


Fig. 31:9

Method

1. (a) Set up the electrolytic cell as in experiment 25, and allow a current of known strength to flow for one minute. Measure the length of the oxygen column collected over the anode.
   (b) Repeat part 1 (a) allowing the current to flow for two minutes, three minutes, etc.

2. Repeat part 1 (a) using a current of one-half the strength, twice the strength etc., of that previously used.

Observations

1. CURRENT STRENGTH CONSTANT

Time Current Flows (min.)					
Length of Oxygen Column (cm.)					

2. TIME CONSTANT

Current Strength (amp.)					
Length of Oxygen Column (cm.)					

Conclusion

What factors affect the amounts of materials liberated at the electrodes during electrolysis?

EXPERIMENT 28

To determine the strength of an electric current using a copper voltameter. (REF. SEC. V:44)

Apparatus

Copper voltameter, copper sulphate solution, ammeter, rheostat, switch, source of direct current, stop-watch, balance, alcohol, emery-paper.

Method

1. Clean the cathode with the emery-paper. Wash it in water. Dip it in alcohol and let it dry by evaporation. Weigh it accurately.
2. Arrange apparatus as in Fig. 26:3. Simultaneously close the switch and start the stop-watch. Take ammeter readings every minute and let the current flow for exactly 15 minutes.
3. Remove the cathode, being careful not to dislodge any of the deposit from it. Rinse in water, dip in alcohol, and allow it to dry as before. Weigh it accurately.

Observations

Ammeter Readings—														

1. Initial weight of cathode = gm.
2. Final weight of cathode = gm.
   ∴ Weight of copper deposited = gm.
3. Time of current flow = sec.
4. Current strength (average of ammeter readings) = amp.

Calculations

1. Determine the weight of copper deposited in 1 second.

2. Knowing that the electrochemical equivalent of copper is 0.000329, calculate the current flowing in the circuit.

Conclusions

1. What was the calculated current?
2. How does it compare with the ammeter reading?
3. Define ampere, coulomb.

Questions

1. What possible sources of error were there in this experiment?
2. Why would a silver voltameter be more accurate than a copper voltameter?

EXPERIMENT 29

To study electroplating. (Ref. Sec. V:45)

Apparatus

Electrolytic cell, copper sulphate solution, copper anode, object to be plated (a key) as cathode, source of direct current, rheostat, emery-paper, carbon tetrachloride.

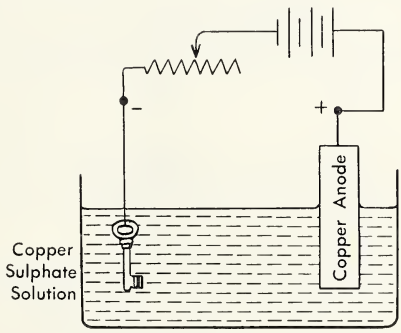


Fig. 31:10

Method

Carefully clean the object with emery-paper, wash in carbon tetrachloride and wash in water. Arrange apparatus as in the diagram. Close the circuit. Adjust the rheostat so that only a small current flows. After several minutes, remove the electrodes and examine them.

Observations

What is observed?

Conclusion

What is meant by electroplating?

Explanation

Write a brief explanation for copper plating.

Questions

1. In order to electroplate with any metal, what must (a) the cathode (b) the anode (c) the electrolyte consist of?
2. (a) Why should the cathode be cleaned?
   (b) Why should a small current be used?
3. Why was there no change in the colour of the copper sulphate solution in the above experiment?

EXPERIMENT 30

To illustrate the principle of the lead-acid storage cell.
(REF. SEC. V:46)

Apparatus

Two strips of lead metal, emery-paper, two dry cells, glass tumbler, solution of sulphuric acid (one part concentrated sulphuric acid added to ten parts water), flash-light bulb, socket, galvanometer with fuse.

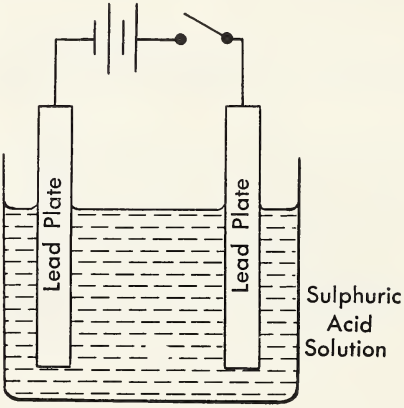


Fig. 31:11

Method

1. Thoroughly clean the lead strips, using the emery-paper. Fill the tumbler about three-quarters full of sulphuric acid solution. Immerse the lead strips in the solution so that they do not touch each other, connect them in series with the dry cells and let the current flow for about 5 minutes. Momentarily insert the galvanometer into the circuit to determine the direction of the current. Note any changes observed at each electrode.

2. Remove the dry cells and insert a flash-light bulb in their place. Note what happens. Momentarily insert the galvanometer to determine the direction of the current again. Let the current continue to flow until the flash-light bulb goes out and note any changes in the plates.

Observations

Describe all observations.

Explanation

1. (a) What type of cell do you have in part 1?
   (b) What energy transformation takes place in it?
2. (a) What type of cell do you have in part 2?
   (b) What energy transformation takes place in it?
3. Describe briefly the chemical changes involved during the above energy transformations.

Conclusions

1. What does a lead-acid storage cell consist of?
2. Describe what takes place during discharging and recharging.

Questions

1. How may a hydrometer be used to determine the condition of a storage battery?
2. Why must water be added to a storage battery periodically? Why should it be distilled water?

EXPERIMENT 31

To investigate the magnetic field surrounding a conductor of electricity. (Ref. Sec. V:48)

Apparatus

Several dry cells, conductor, iron-filings, small magnetic compass, piece of cardboard, switch.

Method

1. Pass the conductor vertically through the piece of cardboard and connect it with the dry cell and switch so that the electrons will flow upward in the conductor when the switch is closed. Sprinkle iron-filings on the cardboard and gently tap it. Note the results.
2. Explore the magnetic field around the conductor with the compass-needle and plot the direction of the needle on a diagram.
3. Grasp the wire with your left hand so that the fingers point in the direction in which the N-poles are deflected. Compare the direction of the electron flow and that in which your thumb points.
4. Reverse the direction of electron flow and repeat the procedure in 3 and 4.

Observations

Describe all observations made above.

Conclusions

1. Describe the magnetic field around a wire carrying electric current.
2. State the Left-Hand Rule.

Question

Describe the magnetic field obtained if the above conductor were coiled into a single loop.

EXPERIMENT 32

To investigate the magnetic field surrounding a helix carrying electric current. (REF. SEC. V:49)

Apparatus

Dry cell, helix, iron-filings, magnetic compass, piece of cardboard.

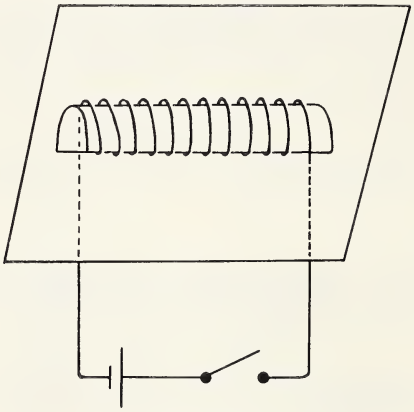


Fig. 31:12

Method

1. Set the helix into a slit in the cardboard and support it horizontally. Join it to the dry cell and switch. Close the switch and sprinkle iron-filings on the cardboard, tapping it gently as you do so. Describe what occurs.
2. Determine the polarity of the magnetic field about the helix, using the N-pole of the compass.
3. Grasp the helix with your left hand so that the fingers point in the direction of the electron flow. Toward which pole does your thumb point?
4. Reverse the direction of electron flow and repeat parts 2 and 3 above.

Observations

Describe all the observations made above.

Conclusions

1. Compare the magnetic field about a helix carrying a current, with that about a bar magnet.
2. State the Helix Rule.

EXPERIMENT 33

To discover the factors affecting the strength of an electromagnet. (Ref. Sec. V:50)

Apparatus

Two dry cells, about 5 ft. of copper wire, cylindrical piece of soft iron about 4 in. long and ½ in. in diameter, compass-needle, small iron weights (tacks, etc.) switch.

Method

1. Wind about 10 turns of wire into a loose coil around the piece of soft "iron". Remove the iron core and join the coil to a dry cell and switch. Close the switch and test the coil for magnetism. Determine the number of iron weights that can be lifted.
2. Insert the soft iron core, close the switch and test as before, noting any difference in the strength of the magnetism.
3. Using twenty turns of magnet wire around the iron core repeat the observations made in parts 1 and 2.
4. Using the two dry cells in series, repeat part 3.

Observations

State the number of iron weights lifted in each of the above cases.

Conclusion

What factors affect the strength of an electromagnet?

Explanation

State why each of these factors increases the strength of an electromagnet.

Questions

The galvanoscope (Fig. 27:14) consists of several coils of wire with different numbers of turns, e.g., 1, 25, 100, in each coil.

1. Describe how this instrument may be used (a) to determine the direction of a current (b) to compare the strengths of different currents.
2. What is the purpose of the coils with different numbers of turns?

EXPERIMENT 34

To determine the effect of a magnetic field upon a conductor carrying electric current. (REF. SEC. V:52)

Apparatus

Battery of dry cells, strong horseshoe magnet, switch.

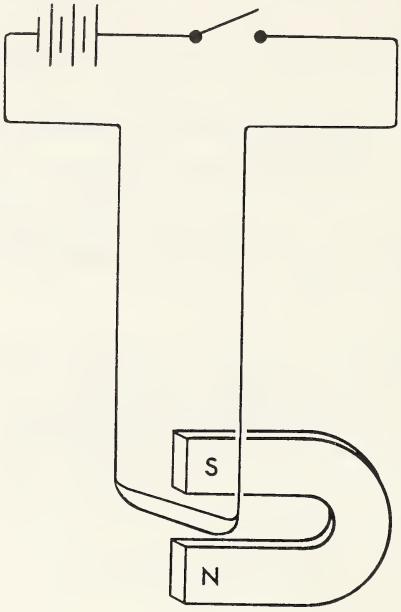


Fig. 31:13

Method

1. Assemble the apparatus as in the diagram with the conductor suspended between the poles of the magnet at right angles to the direction of the lines of force. Close the switch and note what happens.
2. Reverse the direction of the current and repeat part 1.

Observations

Describe what is observed.

Conclusion

What is the effect of a magnetic field upon a conductor carrying an electric current? This is the motor principle.

Explanation

What causes the conductor to move in each case?

Questions

1. If the above conductor were coiled into a helix and freely suspended in a magnetic field, what would be the effect
   (a) When a small current is passed through it?
   (b) When a larger current is passed through it?
   (c) When the current is reversed?
   (d) When the field is reversed?
   Make labelled sketches to indicate polarities and direction of movement.
2. What energy transformation occurs?

Application

Describe the construction of the D'Arsonval galvanometer.

EXPERIMENT 35

To investigate the principle of operation of a simple direct-current motor. (Ref. Sec. V:55)

Apparatus

St. Louis motor (Fig. 27:21), dry cells, rheostat, magnetic compass, switch.

Method

1. Examine the motor carefully. Identify the field magnets, armature, brushes and commutator. Connect the brushes in series with the battery, rheostat and switch. Close the switch and give the armature a gentle push to start it rotating.
2. Remove the magnets. Close the switch and adjust the rheostat so that a small current passes through the armature winding. Determine the polarity of the armature. Note the position of the commutator segments and brushes. Slowly rotate the armature through 180°. Note the changes in the position of the commutator segments and brushes as you do so. Again determine the polarity of the armature. Replace the magnets.
3. (a) Vary the current by changing the rheostat setting.
   (b) Vary the magnetic field by changing the distance of the poles from the ends of the armature.
   What effect do each of these have on the speed of rotation of the armature?
4. (a) Reverse the direction of the current.
   (b) Reverse the direction of the magnetic field.
   What effect do each of these have on the direction of rotation of the armature?

Observations

Describe all the observations.

Conclusions

1. Why does the armature of a direct current motor rotate? What energy transformation takes place?
2. What governs the speed of rotation of the armature?
3. What governs the direction of rotation of the armature?

Explanation

1. What is the purpose of the commutator in a direct-current motor? Explain its action.
2. Explain why the factors mentioned in conclusions 2 and 3 affect the rotation of the armature.

Question

How does this motor differ from commercial D.C. motors?

EXPERIMENT 36

To determine the cause of an induced current. (REF. SEC. V:58)

Apparatus

Galvanometer, two solenoids wound on hollow spools so that one with few turns of wire will slip entirely inside one with many turns, bar magnet, dry cell, switch.

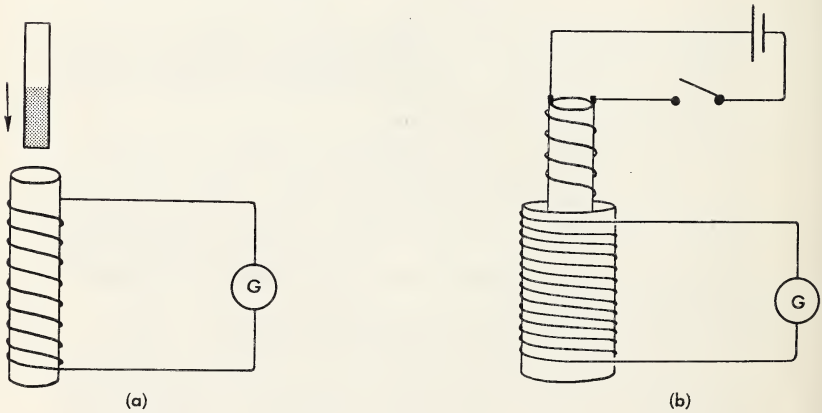


Fig. 31:14

Method

Connect the larger solenoid to the galvanometer.

1. Thrust the magnet into the centre of the solenoid. Keep it stationary for a few moments and then withdraw it quickly.
2. Connect the terminals of the smaller solenoid through a switch to a dry cell. Close the circuit. Thrust smaller solenoid into the centre

of the larger. Leave it stationary for a few moments and then withdraw it.

3. Place the smaller solenoid (the primary coil) inside the larger one (the secondary coil), and close the primary circuit. After a few moments open the circuit again.

Observations

Observe the galvanometer needle at each stage of the experiment.

Conclusion

State the cause of an induced current.

EXPERIMENT 37

To determine what factors affect the magnitude of an induced electromotive force (E.M.F.). (Ref. Sec. V:59)

Apparatus

Same as for experiment 36, iron core to fit in hollow core of primary coil.

Method

1. With the larger solenoid attached to the galvanometer, insert the bar magnet into the hollow core first slowly and then rapidly. Compare the strengths of the induced E.M.F.'s.
2. With the larger solenoid attached to the galvanometer plunge the bar magnet into its hollow core. Then attach the galvanometer to the solenoid with fewer turns of wire and plunge the bar magnet into it at the same speed as before.
3. Attach the larger solenoid to the galvanometer. Connect the smaller solenoid (primary coil) to the dry cell to make an electromagnet. Plunge the electromagnet into the hollow core of the secondary coil. Now insert the iron core into the centre of the primary coil and plunge the primary into the secondary.

Observations

State what is observed in each part above.

Conclusion

What factors affect the magnitude of an induced E.M.F.?

Question

Why were the induced currents produced at the "make" and "break" of the primary circuit in experiment 36 much greater than those produced by other means?

EXPERIMENT 38

To investigate the direction of an induced E.M.F. (Lenz's Law). (Ref. Sec. V:61)

Apparatus

Solenoid with many turns, bar magnet, galvanometer, dry cell, high resistance.

Method

1. Connect the dry cell through the high resistance to the galvanometer. Note in what direction the galvanometer needle is deflected when a current of known direction is passing through it.
2. Connect the solenoid to the galvanometer and note the direction of the needle deflection and thus determine the direction of the current when:
   (a) The N-pole of the magnet is thrust into the coil.
   (b) The N-pole is withdrawn.
   (c) The S-pole is inserted.
   (d) The S-pole is withdrawn.
3. Using the Helix Law, determine the polarity of the upper end of the solenoid for each part of 2.

Observations

OPERATION	DIRECTION OF CURRENT ACROSS FRONT OF SOLENOID	POLARITY OF UPPER END OF SOLENOID
N-pole inserted		
N-pole withdrawn		
S-pole inserted		
S-pole withdrawn		

Conclusions

1. What effect does the magnetic field produced have on the motion that is inducing the current?
2. State Lenz's Law.

Questions

1. Make a series of diagrams to illustrate the above observations. Show the direction of motion of the magnet and the polarity produced.
2. Use Lenz's Law to explain the production of an induced E.M.F. at the make and break of a primary circuit (Experiment 36, part 3).

EXPERIMENT 39

To demonstrate the production of an alternating current and to study the principle of the A.C. and D.C. generator.
(REF. SEC. V:61 to 63)

Apparatus

Earth inductor (Fig. 28:4), galvanometer, connecting wires, St. Louis motor with both A.C. and D.C. armatures (Fig. 27:21).

A. Using the Earth Inductor

Method

Connect the two leads of the earth inductor to the terminals of the galvanometer. Rotate the coil rapidly through 360° and note the action of the galvanometer needle.

Observations

State what is observed.

Explanation

1. What is the cause of the induced E.M.F.?
2. Why does it vary in direction throughout the 360° rotation? Illustrate your answer by a series of diagrams.

Conclusion

What is produced by each complete rotation of a coil in a magnetic field?

B. Using the St. Louis Motor Model

Method

1. Connect the leads from the A.C. armature to the galvanometer. Spin the armature with the finger and note the action of the galvanometer needle.
2. Replace the A.C. armature with the D.C. armature. Spin the armature as before and again note the action of the galvanometer needle.

Observations

State what occurred.

Explanation

1. Answer the questions found in the explanation in part A.
2. How is the induced alternating current carried to an external circuit?
3. How may this induced alternating current be changed to direct current? Name and describe the device used to do this.

Conclusions

1. What is a generator?
2. What energy transformation occurs in the operation of a generator?
3. What is the difference between an A.C. and a D.C. generator?

Questions

1. How could you produce 60 cycle A.C. with the model used in this experiment?
2. What modification in the structure of the apparatus would permit a reduction in the speed of rotation of the armature in question 1?

EXPERIMENT 40

To study self-inductance. (REF. SEC. V:67)

Apparatus

Coil with many turns wound around a soft iron core, three dry cells, switch, 6-volt lamp, neon lamp and socket.

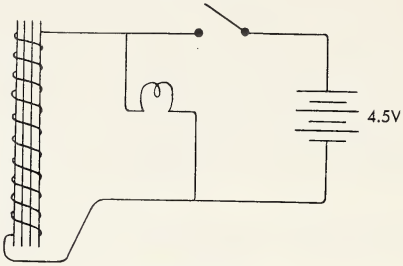


Fig. 31:15

Method

1. Connect the coil in series with the dry cells and switch as shown in the diagram. Join the lamp in parallel with the coil.
2. Close the switch. Note the effect on the lamp.
3. Open the switch. Note the effect on the lamp.

Observations

Make note of the observations.

Explanation

With the aid of Lenz's Law account for the phenomena noted above.

Conclusion

What is meant by self-inductance?

Question

What causes the arc when a switch is opened?

EXPERIMENT 41

To demonstrate the conductivity of a gas (An introduction to electronics). (REF. SEC. V:77)

Apparatus

Gold-leaf electroscope, ebonite rod, cat's fur, glass rod and silk, Bunsen burner.

Method

1. Charge the electroscope positively. Hold a flame near the knob of the electroscope. Note what happens.
2. Charge the electroscope negatively and repeat step 1.

Observations

Describe what is observed in each part above.

Explanation

What effect did the flame have on the particles of gas causing it to become a conductor of electricity? Why were both the positively and negatively charged electroscopes discharged?

Conclusion

What is electronics?

EXPERIMENT 42

To study the changes in the conductivity of a gas as its pressure is reduced. (Ref. Sec. V:77)

Apparatus

Electrical discharge tube with open side-arm (Fig. 30:1), vacuum-pump, induction coil, battery.

Method

Attach the electrodes of the discharge tube to the terminals of the secondary of the induction coil. The discharge points of the induction coil should be close together. Turn on the induction coil and evacuate the tube as completely as possible with the vacuum-pump. Note what happens.

Observations

1. Where did the electrical discharge occur before and after evacuation of the tube?
2. Describe the discharge in the tube at various stages of evacuation.

Explanation

Why does the discharge occur in the evacuated tube rather than between the discharge points?

Conclusion

What effect does reducing the pressure of a gas have on its electrical conductivity?

Question:

According to the electron theory, what constitutes the current of electricity (a) through a gas at ordinary or reduced pressures (b) through a vacuum?

EXPERIMENT 43

To study some properties of cathode rays. (Ref. Sec. V:78)

Apparatus

Crookes' tube (Fig. 30:2b), induction coil, dry cells, bar magnet.

Method

1. Set up apparatus as in diagram. Darken the room. Complete the circuit and observe the appearance of the end of the tube remote from the cathode.
2. Erect the target or metal cross in the path of the rays and again observe as in part 1.
3. Approach the sides of the tube with first the N-pole and then the S-pole of the bar magnet and observe as above.

Observations

Describe what is observed.

Conclusion

List three properties of cathode rays.

Question

What evidence is provided in part 3 above to prove that cathode rays are streams of electrons?

EXPERIMENT 44

To study the production and nature of X-rays. (REF. SEC. V:79)

Apparatus

X-ray tube (Fig. 30:3), induction coil, gold-leaf electroscope.

Method

1. Join the secondary terminals of the induction coil to the anode and cathode of the X-ray tube. Charge the electroscope and place it with its knob near the target of the tube. Start the induction coil and observe the leaf of the electroscope.
2. Repeat the above procedure placing (a) a piece of cardboard (b) a piece of wood (c) a piece of lead plate between the knob of the charged electroscope and the X-ray tube.

Observations

State what is observed in each case above.

Conclusions

1. How are X-rays produced?
2. Account for the above observations.

EXPERIMENT 45

To study thermionic emission of electrons in a vacuum-tube. (REF. SEC. V:80)

Apparatus

Diode tube (D), two switches (K_1 and K_2), "A" battery, "B" battery, galvanometer (G).

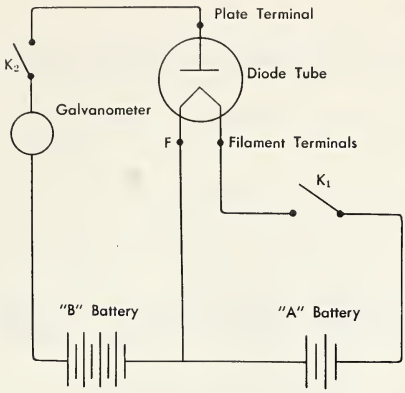


Fig. 31:16

Method

1. Connect the circuit as shown in the diagram using the plate and filament voltages recommended for the tube available.
2. With K_1 open—
   (a) close K_2 making the plate positive and watch the galvanometer for any deflection.
   (b) reverse the terminals of the "*B*" battery so the plate is negative and repeat part (a).
3. With K_1 closed—
   (a) close K_2 making the plate positive and note any galvanometer deflection.
   (b) reverse the terminals of the "*B*" battery so the plate is negative and repeat part (a).

Observations

	Switch K_1	Plate Charge	Galvanometer Deflection
2(a)			
2(b)			
3(a)			
3(b)			

Explanation

1. Explain the effect on the filament of closing switch K_1.
2. Account for the above observations.

Conclusions

What two conditions must be fulfilled so that electrons will flow through a vacuum-tube?

EXPERIMENT 46

To demonstrate rectification by a diode tube. (REF. SEC. V:80)

Apparatus

Diode tube, two 45-volt "*B*" batteries, "*A*" battery, neon bulb.

Method

1. Connect the two "*B*" batteries in series and join these to the neon bulb. Reverse the battery connections.
2. Connect the neon bulb to the 110-volt alternating-current outlet.
3. In the circuit shown in experiment 45 replace the "*B*" battery by the 110-volt alternating-current source, and the galvanometer by the neon bulb.

Observations

Describe the way in which the neon bulb glows in each step above.

Explanation

Account for each observation.

Conclusions

1. What is meant by rectification?
2. Explain how rectification occurs in the diode tube.
3. Make a diagram to illustrate the direct current produced in the plate circuit on the diode tube in step 3.

EXPERIMENT 47

To demonstrate photo-emission of electrons. (REF. SEC. V:82)

Apparatus

Zinc plate, gold-leaf electroscope, arc-lamp.

Method

1. Attach the knob of the electroscope to the zinc plate by a fine wire. Charge the zinc plate negatively. Allow the beam of light from the arc-lamp to fall upon the charged zinc plate.
2. Repeat part 1 with the zinc plate positively charged.

Observations

What is observed in each step above?

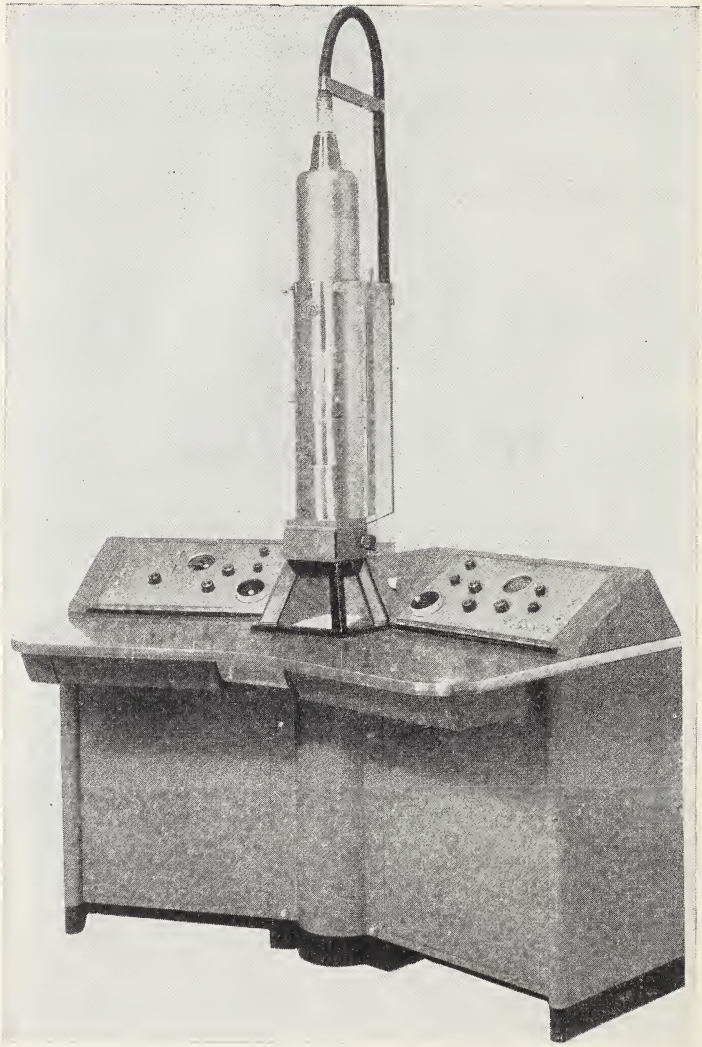
Explanation

Account for the observations.

Conclusions

What is meant by photo-emission of electrons?

MODERN DEVELOPMENTS IN PHYSICS



R.C.A. Victor Company, Ltd.

This Electron Microscope Permits Viewing of Particles Smaller Than One 10-Millionth of an Inch in Any Diameter. It Provides Magnification 50 Times Greater Than Heretofore Possible—So Great That a Human Hair Would Take on the Dimensions of a Subway Tunnel.

CHAPTER 32 MODERN DEVELOPMENTS IN PHYSICS

THIS TWENTIETH CENTURY

This has been called the age of Physics —a time when apparent luxuries have become commonplace necessities or gadgets of research have become ordinary articles of commerce. This century has seen the "horseless carriage", originally a luxury, become a necessity for business and pleasure. The airplane in one generation has undergone an amazing development for peace and war. Electronics has given birth in turn to radio, radar and television.

In this chapter, a few modern developments are to be described. These are

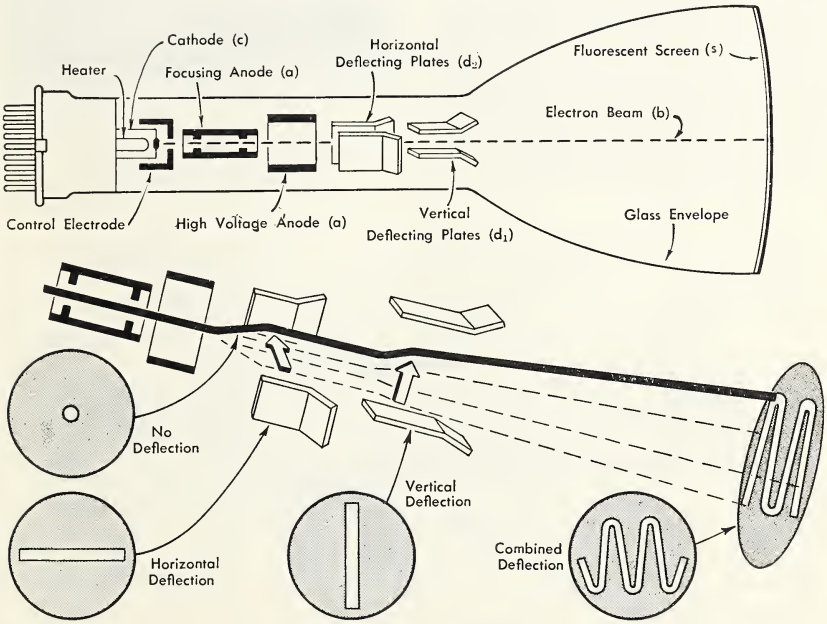


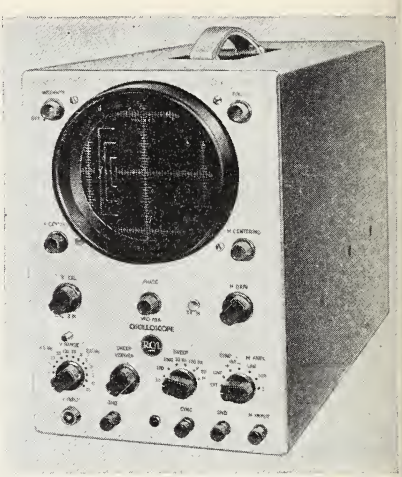
Fig. 32:1 The Cathode Ray Tube.

selected because the preceding chapters serve as a preparation for them and because they are topics that will be of considerable interest to many students.

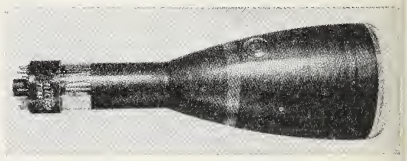
Cathode-Ray Oscilloscope

The principle of the cathode-ray tube (Sec. V:78) is shown in Fig. 32:1. Electrons emitted by the hot cathode (*c*) travel at high speed toward the anode (*a*). Many pass through the opening in the anode and form the electron beam (*b*) which passes between the two sets of deflecting plates (d_1 d_2) and impinge on the fluorescent screen (*s*). A spot of light appears on the screen wherever the electron beam strikes.

The spot of light is made to travel by applying voltages to the deflecting plates, thus causing the electron beam to sweep from side to side, move up and down, or undergo both motions simultaneously. Each point on the screen struck by the beam continues to fluoresce for a short time after the beam has gone by and does not quite die out before the next passage of the beam revives it. This fact combined with persistence of vision



RCA Victor Company, Ltd.



Canadian Marconi Co.

Fig. 32:2 Commercial Cathode Ray Oscilloscope and Tube.

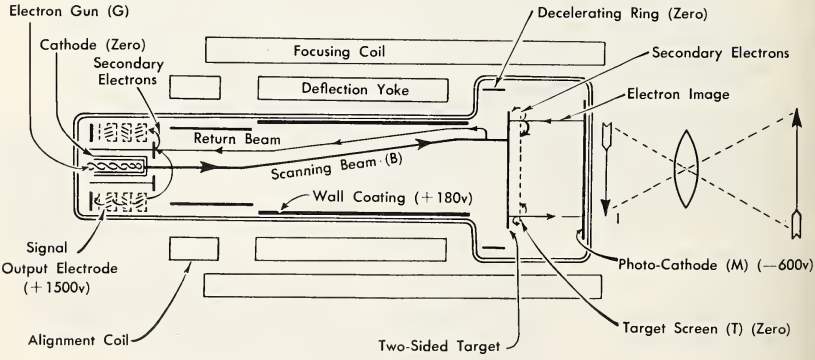
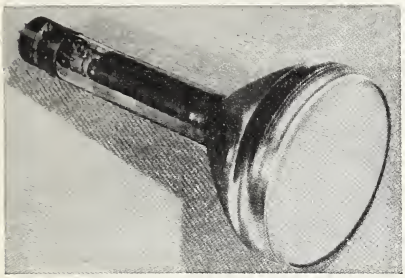


Fig. 32:3 The Image Orthicon.

of the human eye produces the illusion of a continuous line of light on the screen. Thus, it is easy to see that if one voltage is used to make the beam sweep from side to side at a known uniform rate, another voltage applied to the vertical deflection plates will make the spot write the autograph of the latter voltage on the screen, revealing in graphic form its frequency, wave form and other characteristics.



Illus. Courtesy of Canadian Marconi Co.

A Picture Tube

The commercial cathode-ray oscilloscope and tube is pictured in Fig. 32:2. It combines in one circuit a cathode-ray tube, a sweep circuit, amplifiers, a power supply, all properly synchronized. This is probably the most widely used instrument in electronics, particularly in the testing and repair field. All kinds of sound—speech, noise, music—can be analyzed by the use of this instrument.

Television

In radio, electromagnetic waves modulated by the original sound-effects are transmitted through space. In television, a picture controlled by the light from the scene is transmitted at the same time as the sound. The feeble energy from such waves controls electric currents and magnetic fields in such a way as to reproduce the original sound and scene.

In the modern television camera, the essential component is an image orthicon, Fig. 32:3, not much bigger than a rolled-up magazine, but very complicated, sensitive and costly. It receives an optical image, *I*, of the scene on a thin metal coating, *M*, on the inside surface of the tube. Electrons are ejected from this screen in direct propor-

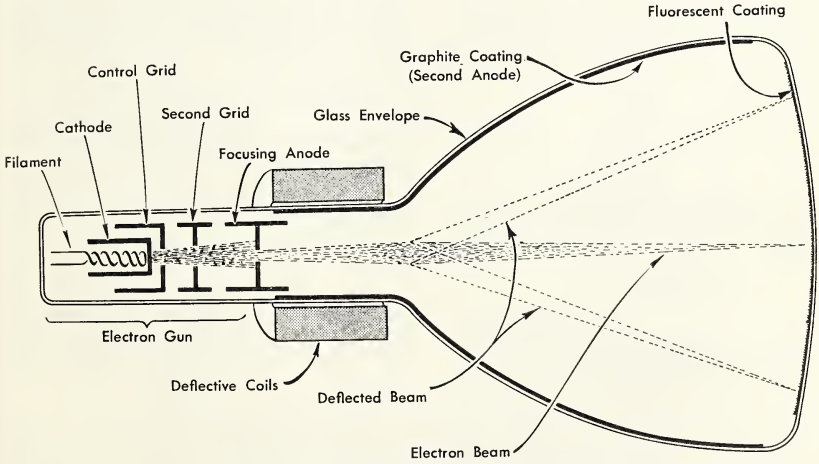
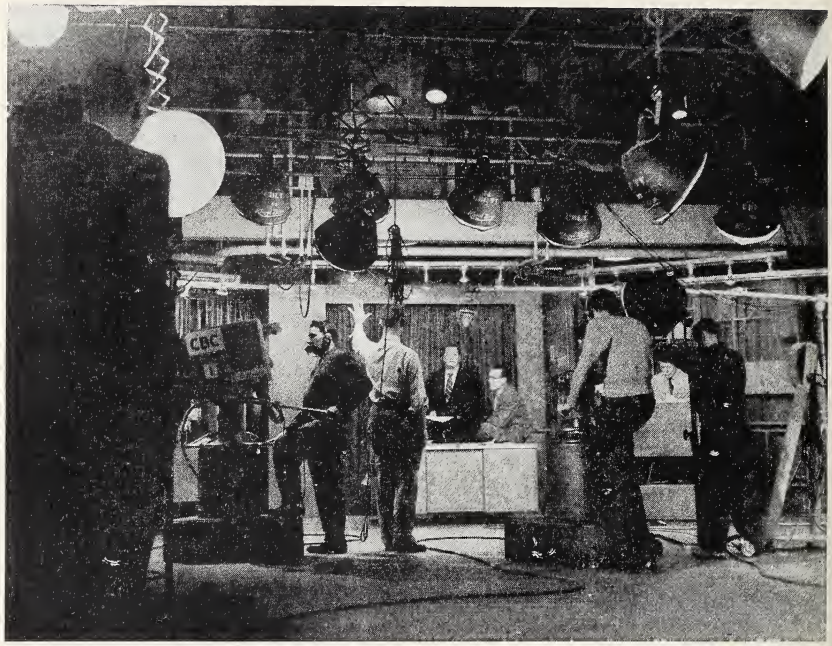


Fig. 32:4 The Kinescope (Picture Tube)



Canadian Broadcasting Corp.

Scene in Television Studio During a Broadcast.

tion to the brightness of the light that falls on it. These collect on the target screen, *T*, nearby and produce an elec-

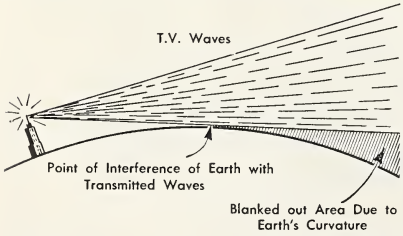
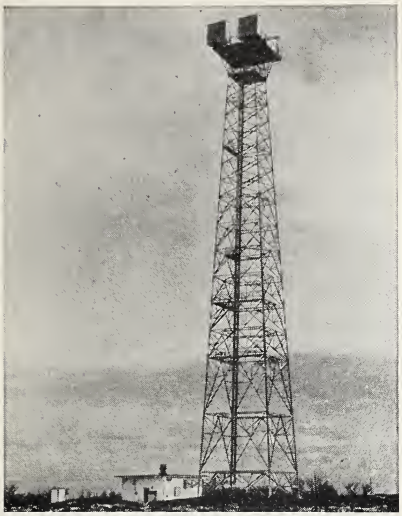


Fig. 32:5 The Effect of the Earth's Curvature on Television Waves.

tron image of the scene. This electron image is scanned by an electron beam, *B*, from the electron gun, *G*, in much the same manner as you read a page in this book but much faster (covering 525 lines in 1/3 sec.). The beam is controlled as in the cathode-ray tube. The speed of the electrons in the beam is so regulated that some of the electrons are repelled in a return beam whose intensity varies with the concentration of electrons on the target screen and, consequently, with the brightness of light from the scene. This return beam constitutes a weak current which is amplified, sent to a transmitter where it modulates ultra high frequency carrier waves that are broadcast much as are radio waves.

The main part of the receiving apparatus is another cathode-ray tube, called a kinescope (Fig. 32:4), that is

essentially the same as in the cathode-ray oscilloscope. The signal received by the antenna is amplified and then is applied to the tube in a manner that controls the intensity of the electron beam shot out by its electron gun. The motion of this beam is synchronized with the scanning of the image orthicon. Since the intensity of the beam and hence the brightness of the spot on the screen varies with the signal received, the beam produces a reproduction of the original scene 30 times per second. The illusion of a continuous picture is explained by the rapidity of scanning and our persistence of vision.



Bell Telephone Company of Canada

Fig. 32:6 A Relay Station.

Television waves travel in a straight path. Each transmitter's coverage is an area with a radius of about 130 miles on account of the earth's curvature (Fig. 32:5). Obviously, this presents a problem in telecasting events of national importance from coast to coast. To overcome the difficulty a series of relay stations (Fig. 32:6) has been developed which is used both for television and telephone conversations using short waves called microwaves to carry the energy. Each frequency carries several messages. Waves of this kind can be focused and aimed at the next station so that little energy is lost.

The sound system of television is of the type called frequency modulation (F.M.) unlike that of ordinary radio which is amplitude modulation (A.M.). In the latter, the signal modulates (alters

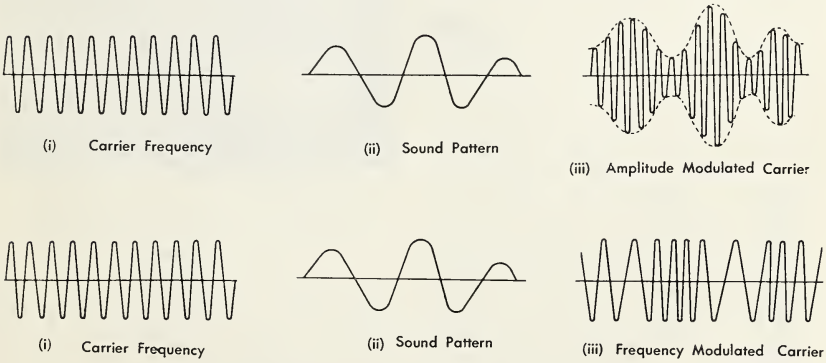


Fig. 32:7 (a) Amplitude Modulation.
(b) Frequency Modulation.

the form of) the amplitude of the carrier wave as in Fig. 32:7a. Such a wave is affected by all kinds of outside electromagnetic disturbances (static). In the former, the signal modulates the frequency of the carrier wave as in Fig. 32:7b. Such a wave is free from static.

In one method for colour television, the camera has three separate orthicons operating behind red, green and blue filters respectively and giving rise to three different signals. In the receiver each signal puts its own corresponding component of the picture tube into operation. The end of the picture tube is dotted with "phosphors" that will glow red, green or blue, when properly stimulated. When all three phosphors are made to glow by their respective electron beams, the original scene is reproduced in full colour.

Radar

The word radar is a contraction of the words Radio Detection And Ranging which gives a good idea of what it means. Man has known for centuries that echoes are useful in detecting distant obstacles and determining their position. We know that the bat uses the echo of his high-pitched squeak to enable him to avoid objects as he flies back and forth in the dark. Mariners have used the echo of the ship's whistle to locate shorelines and icebergs. High frequency radio waves (300 to 3000 megacycles per second) are used for the same purpose in radar. At these frequencies they resemble light waves and can be reflected, refracted and focused. Like light they travel in straight lines. The radar principle, first used in 1924 in exploring the upper regions of the earth's atmosphere was adapted by Sir Robert Watson Watt for the location of aircraft, ships and shorelines in World War II. It was this device which enabled those few valiant defenders of the British Isles (and of the freedom of the world) during the Battle of Britain to earn those remarkable words of Sir Winston Churchill when he said, "Never . . . was so much owed by so many to so few".

In the chapters on sound, we learned that the distance from an observer to an object may be computed if we know the time required for sound to travel to it and for the echo to return (Sec. II:7). Similarly, the distance of an aircraft may be determined by sending out a pulse of high-frequency radio waves, *P*,

Fig. 32:8 (a) Using Radar in Aircraft Detection.
(b) View of Screen of Receiver.

Fig. 32:8a, from the transmitter, *T*, and detecting the reflected impulse, *E*, by a receiver, *R*. If the time interval required is determined and the velocity of radio waves (186,000 mi. per sec.) is known, the distance may be determined.

The receiver contains a cathode-ray tube in which the spot is made to traverse the screen at a constant known speed. The outgoing and echo signals generate voltages which are applied to the vertical plates and produce upward jolts or "blips" on the trace (Fig. 32:8b). The distance between these blips enables the operator to calculate the time interval.

To specify the position of an aircraft we must know the bearing and the elevation. The former is detected by comparing the strength of the echo signals from two sending aerials set at right angles. The elevation can be determined

Canadian Aviation

This Radar Screen Has Picked Up a Typhoon.

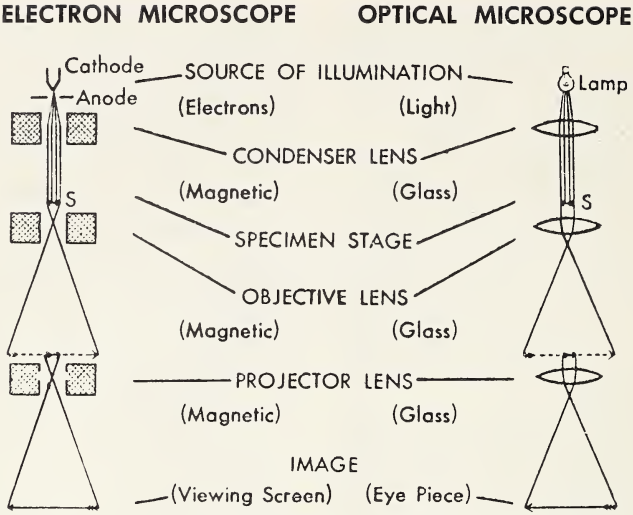
with the aid of two aerials each above the other. To recognize friendly aircraft the radar pulse triggers a special transmitter and consequently the return pulse will be given a special mark which is distinguished on the cathode-ray tube.

Radar has numerous peace-time applications. It is used to follow the flight of aircraft flying over lonely or thinly-populated areas like the far north. Aerial and water transport employ it at night and in fog to avoid striking obstacles. Highway traffic authorities find it valuable in tracking down speeding drivers.

The Electron Microscope

It can be shown that the ability of a microscope to reveal the fine detail of an object (the resolving power) is limited by the wave-length of the light used. Consequently, the practical upper limit of magnifying power that can be obtained with optical microscopes—using visible light—is about 2000 diameters. Now it is known that an electron stream behaves in a manner very similar to a light beam but with an effective wave-length some 10,000 times smaller, permitting examination of bacteria, viruses and very large molecules.

Accordingly scientists, especially Dr. F. Burton and his associates at the University of Toronto in the 1930's explored the possibility of using electrons in microscopy. As a result of their researches the electron microscope, shown diagrammatically in Fig. 32:9, was developed. The electrons are produced by a heated cathode and are accelerated under a potential of some 50,000 volts applied to an anode with a central hole from which they emerge in a stream of swiftly moving electrons. The electron stream is converged and focused by magnetic and electric fields much as light is by glass lenses in an optical microscope. These "magnetic lenses" consist of short solenoids entirely encased in a steel shield except for a narrow gap in the centre through which the electrons pass and where they become deflected. The arrangement of lenses is similar to that in the optical microscope but the object to be studied is very much thinner (1/100,-



R.C.A. Victor Company Ltd.

Fig. 32:9 A Comparison of Electron and Optical Microscopes.

000 cm. thick). The instrument must be evacuated to prevent deflection of the electron stream as it collides with air molecules. The varying penetrations of the electrons through the object produce a sort of shadow picture on the fluorescent viewing screen or photographic film. Magnifications of up to 100,000 diameters have been obtained.

The electron microscope has proved to be a very valuable tool in the hands of the research worker. It has revealed new facts about particle shapes and sizes which affect such processes as the covering power of paint pigments, the wearing quality of rubber tires and the operation of chemical catalysts. It has

COMPARISON OF SOME MAGNIFIERS

Object	*Diameter (Microns)*	*Magnification (Diameters)*	*Instrument*
Fine Machine Work	25-100	8	Hand lens
Pond Life Fungi	10-25	20	Low power optical
Bacteria	1-2	200	Medium power optical
Structure of Bacteria	0.25	1000.	High power optical
Large Virus	0.10	2000.	Special optical microscope or electron microscope
Colloidal Particles	0.05	4000.	Electron microscope
Small Viruses	0.01	20,000	Electron microscope
Large Molecules	0.002	100,000	Electron microscope

provided new information in such fields as metallurgy, chemistry, ceramics, crystallography, plastics, textiles, biology and medicine.

NUCLEAR PHYSICS

In Section V:12, the composition of the atom was presented without any supporting evidence. There the components — electrons, protons, neutrons, nucleus, orbits — were defined. This knowledge of the atom came about by a process of gradual evolution. First was the discovery of the electron by Sir J. J. Thomson as a result of his work on cathode rays (Sec. V:78). Later, studies on radioactivity contributed much to knowledge about the nucleus of the atom.

Radioactivity

In 1896 the French physicist Becquerel noticed that salts of uranium affected a neighbouring photographic plate. He concluded that these salts must be emitting rays or particles spontaneously generated by the salts themselves. This phenomenon was called radioactivity and was extensively investigated by Pierre and Marie Curie. Using pitch-blende, a natural ore rich in uranium compounds, they succeeded, after a long series of repeated crystallizations, in isolating two new elements, polonium and radium, which were more radioactive than uranium. Later work by the Curies and others has revealed, indeed, that quite a number of the heavier elements are radioactive.

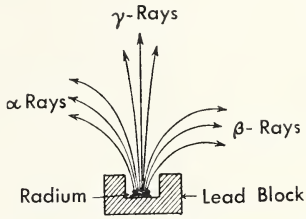


Fig. 32:10 Radium Emanations.

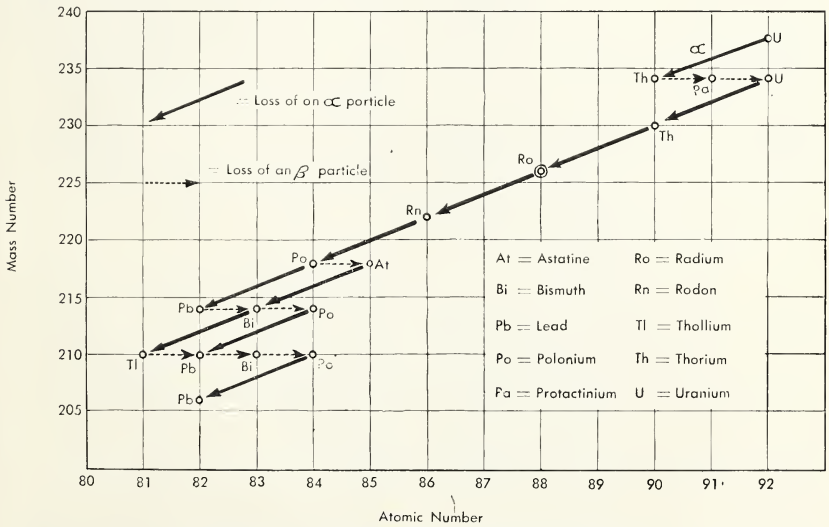


Fig. 32:11 The Uranium Disintegration Series.

In 1903 Rutherford undertook a careful examination of the nature of the radiation from radioactive substances. He showed, by applying a magnetic field, Fig. 32:10, that the radiation could be resolved into three distinct groups of rays which he called alpha (α), beta (β), and gamma (γ) rays, the α-rays being deflected in one direction, the β-rays in the opposite direction, while the γ-rays do not undergo deflection. Further experiments showed that the α-rays were positively charged helium nuclei, the β-rays, negative electrons, and that the γ-rays were highly penetrating, short wave-length, energy waves. Rutherford came to the conclusion that the nuclei of radioactive substances are spontaneously disintegrating into the above rays and changing into new elements as they do so. Fig. 32:11 shows the sequence of changes through which uranium goes as it gradually changes into lead.

The Structure of the Atom

Rutherford found that α-particles would pass through a thin sheet of metal, and concluded that there was considerable empty space in the atom. His concept of the atom was a miniature solar system consisting of electrons revolving about a positively charged nucleus. Later, while at McGill University, he was able to isolate the hydrogen ion or proton. Moseley's experiments, in England, with X-ray phenomena on various elements, indicated the presence of these protons in every nucleus and a different number in the nuclei of different elements. The number of protons in the nucleus of the atom is the **atomic number** or **nuclear charge.** Since the atom is electrically neutral, the

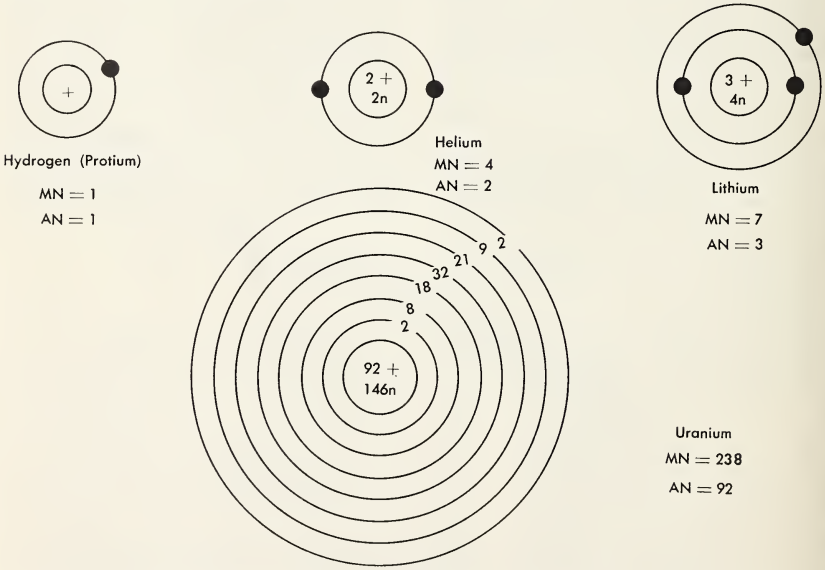


Fig. 32:12 Structure of Some Atoms. (MN = Mass Number; AN = Atomic Number)

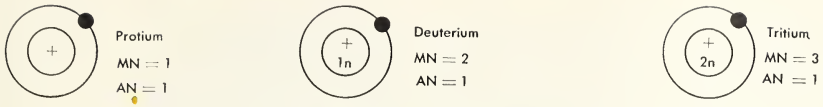


Fig. 32:13 Isotopes of Hydrogen.

number of electrons revolving about the nucleus must equal the number of protons in the nucleus, and hence must also equal the atomic number.

Rutherford's atom served until the discovery by Sir James Chadwick in 1932 of the neutron. This particle (which was earlier predicted by Rutherford) has the same mass as the proton but possesses no charge. It is now believed that atomic nuclei are built up of protons and neutrons. The sum of the protons plus the neutrons make up what is called the **mass number** of the atom. In general the number of neutrons in the nucleus is equal to the mass number minus the nuclear charge or atomic number. For example, the helium nucleus which has an atomic number of 2 and a mass number of 4 must contain 2 protons and 2 neutrons.

Finally, to complete the picture of the atom, Niels Bohr postulated that the electrons revolved in various orbits, or energy levels, about the nucleus. The Bohr Concept for a number of typical atoms is shown in Fig. 32:12.

Isotopes

About this time, it was discovered by Rutherford and Aston in England that although all atoms of an element have the same chemical properties some differed from others in mass. Such forms of any element are called **isotopes.** They postulated that all the isotopes of any one element must have the same number of protons and electrons and hence the same atomic number, but must differ in the number of neutrons in the nucleus and hence must differ in mass number. Most elements consist of a number of isotopes. For example, hydrogen is thought to consist of a mixture of three isotopes (Fig. 32:13). Protium is the commonest isotope of hydrogen. Deuterium is the isotope of hydrogen that is found in heavy water. The nucleus of deuterium, called a deuteron, is much used in experimental work in nuclear physics. Tritium is a very rare isotope of hydrogen that is of importance in the hydrogen bomb.

Artificial Transmutation

The above interpretation of natural radioactivity suggested to Rutherford the possibility of bringing about the disintegration of other nuclei. This was accomplished by Rutherford in 1919 while at McGill by using α-particles from a radioactive source to bombard nitrogen atoms. As a result of the collisions he found that some of the nitrogen atoms had a proton ejected from them, the α-particle remaining with the disrupted nucleus. These atoms therefore had a net increase of 1 proton and 2 neutrons and hence became oxygen atoms (actually a heavy isotope of oxygen):

$$\underset{7}{\overset{14}{N}} + \underset{2}{\overset{4}{He}} \rightarrow \underset{1}{\overset{1}{P}} + \underset{8}{\overset{17}{O}}$$

Thus was achieved the first artificial transmutation of the elements—the old alchemists' dream becoming a reality!

Rutherford next considered the use of artificially energized particles as a more effective means of bringing about nuclear changes, using protons accelerated under a potential difference of about half a million volts. These high-speed protons were directed on to a lithium target,

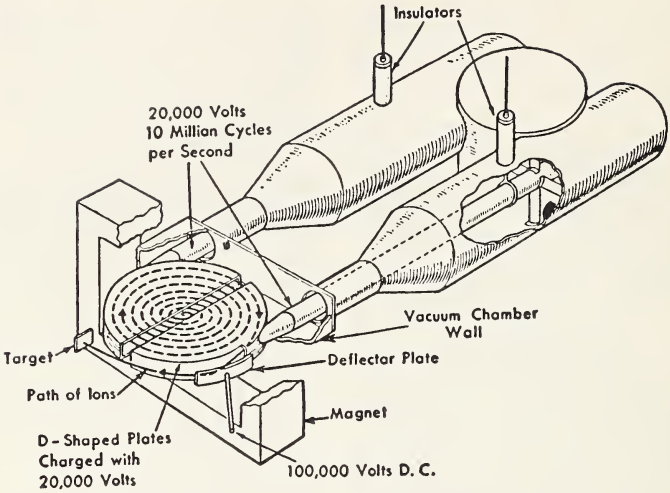


Fig. 32:14 Diagram of a Cyclotron.

some of the atoms of which were split up to form helium atoms:

$$\underset{3}{\overset{7}{Li}} + \underset{1}{\overset{1}{P}} \rightarrow \underset{2}{\overset{4}{He}} + \underset{2}{\overset{4}{He}}$$

Other light elements were disintegrated by this means, but it was realized that even more energetic particles were required to attack the nuclei of heavier elements on account of the large forces of repulsion between the bombarding particles and the larger nuclear positive charge. Particles having the necessary energy for this purpose can be produced by means of the cyclotron (Fig. 32:14). This latter machine, first invented by the American physicists Lawrence and Livingston in 1930, is capable of rapidly accelerating charged particles such as protons and deuterons.

Nuclear Fission

The discovery of the neutron provided physicists with a most effective projectile with which to bombard atomic nuclei because, having no charge, a neutron can approach the positive nucleus of an atom without any repulsive force. A common way of producing neutrons for this purpose is to bombard beryllium metal by a beam of fast-moving deuterons from a cyclotron—neutrons being knocked out of the beryllium nuclei. It was while bombarding uranium 235 (a light unstable isotope of uranium) with neutrons in 1939, that Hahn and Strass-

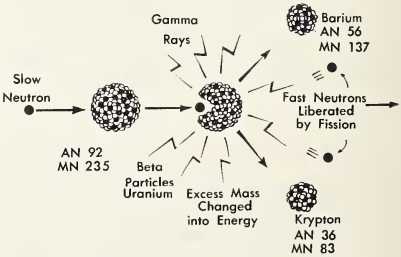


Fig. 32:15 Nuclear Fission.

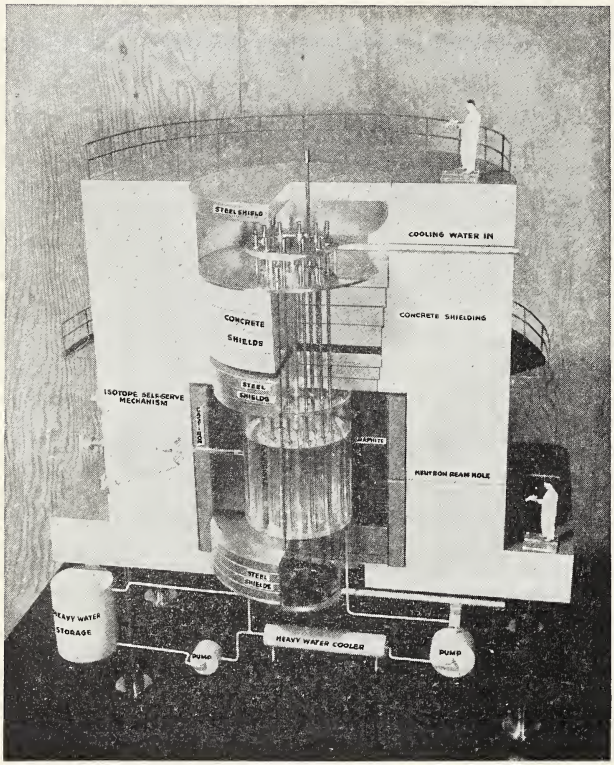
mann discovered an entirely new form of nuclear transformation, Nuclear Fission, in which the uranium nucleus was split into two nearly equal parts with the release of a large amount of energy (Fig. 32:15). Another interesting feature of the fission of uranium is that during the process further neutrons are emitted in relatively larger numbers than those absorbed. Thus from each uranium nucleus undergoing fission two or more neutrons are released. The neutrons so released can then cause fission in other uranium nuclei and so on causing a chain reaction. If allowed to proceed in this way, provided that there is a suitable amount of fissionable matter present, the whole of the material is transformed in a very short time, with the release of vast quantities of energy. This is the principle of the atomic bomb. It has been proven that the combined mass of the products is a little less than the mass of original material. Dr. Albert Einstein as early as 1905 using his famous equation, $E = MC^2$, predicted what we now know—that the mass lost becomes transformed into the energy of the explosion. E represents the energy, M the loss in mass and C, a constant quantity equal to the speed of light (Sec. IV:6). Thus we can see that a small amount of mass is transformed into a tremendous amount of energy.

Nuclear Reactors

If the neutrons from the fission of U 235 are absorbed or slowed down as they are produced, the chain reaction can be controlled and the energy released put to useful purposes. Graphite and certain other light substances which possess the property of absorbing neutrons, are used to control the rate of neutron emission in atomic fission and are called moderators. The assembly of uranium (or other fissile material) and graphite (in the form of blocks or rods) is known as an atomic pile or nuclear reactor (page 402), the rate of energy release being controlled by adjusting the length of the graphite rods inserted in the pile. The energy released is transformed into heat which is used for various purposes. Energy is variously measured. The engineer may express it as B.T.U. per pound (Sec. III:20). The nuclear physicist may express it in electron volts per atom. One B.T.U. equals 665×10^{13} million electron volts. It is estimated that, if coal gives 13,600 B.T.U. per pound, this is 4 electron volts per atom of carbon. By comparison one atom of uranium produces 200 million electron volts. This means that one atom of uranium produces 50 million times as much energy as one atom of carbon or if you have equal masses of coal and uranium the amount of energy released from the uranium is 3 million times as great. There is little wonder, therefore, that the search for uranium goes on at a feverish pace.

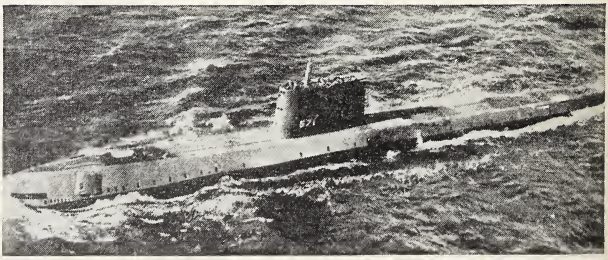
Atomic Fusion

In 1951 when man was congratulating himself on his conquest of the atom through turning fission to his advantage, a new and still more exciting process was evolved by Dr. Edward Teller in the United States. You will recall Hans Bethe's theory of the origin of the sun's continuous heat by the union of four atoms of hydrogen to form an atom of helium accompanied by the conversion of a small amount of mass into energy (Sec. III:3). Dr. Teller employed this process using the isotopes of hydrogen—protium, deuterium and tritium—resulting in the production of a source of energy far greater than ever realized before. The hydrogen bomb was created which was fantastically devastating. A source of energy was born that was so amazing that it may well be the source of energy of the future.



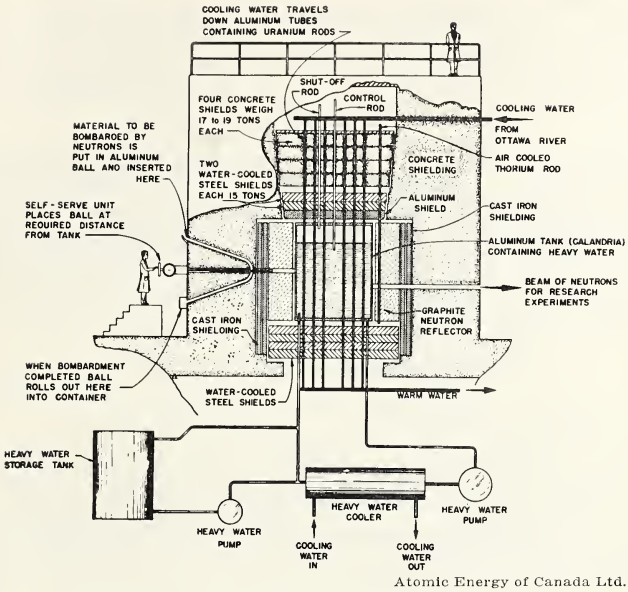
Model of N.R.X. Reactor, Chalk River, Ontario.

Atomic Energy of Canada Ltd.



U.S.S. Nautilus. The First Atomic Powered Submarine.

Star Newspaper Service



Atomic Energy of Canada Ltd.

Diagram of N.R.X. Reactor, Chalk River, Ontario.

Space does not permit dealing at any length with the many and varied uses of atomic energy. Suffice it to say that biological, medical, agricultural and industrial research are greatly benefiting from the developments made in this field as are some users of industrial and domestic power. The possibilities are as yet beyond man's fondest dreams.

ANSWERS

Unit I—Mechanics

Chapter 2, Section I : 4—Page 16

A

4 (a) 1000 mm., 100 c.m., 10 dm., 1000 m. **5** (b) 1,000,000 mg., 100,000 cg., 10,000 dg., 1000 gm. **9** (b) 5, 5, 5, 5, 1, 3. **10** (b) 37., 34., 37. **11** (b) (i) 11.46 (ii) 8.3.

B

1 (a) 1520, 3.8, 605.4 cm.; (b) 30,000, 2.36, 60,005.44 sq. cm.; (c) 2,500,000, 2.3, 6,000,050.465 c.c. **2** (a) 37.4, 15.7, 39.4 in.; (b) (i) 30.5 cm. (ii) 1.61 km.; (c) 100 m. (i) 28.1 ft. (ii) 856 cm.; (d) (i) 58.7 ft. per sec. (ii) 17.9 m. per sec. (iii) 64.4 km. per hr. **3** (a) (i) 1500 sq. cm. (ii) 15. sq. dm.; (b) (i) 22,500 c.c. (ii) 22.5 cu. dm. (iii) 22.5 litres **4** (a) 22,500 gm., 22,500,000 mg., 2,250,000 cg., 225,000 dg., 22.5 kg.; (b) (i) 28.4 gm. (ii) 909. kg. **5** (i) 3.1 litres (ii) 3080 ml. (iii) 5.4 pints **6** (a) 102.70; (b) (i) 66.56 (ii) 71.25 (iii) 67.17; (c) (i) 36. (ii) 0.35 (iii) 27×10^1; (d) (i) 14×10^2 (ii) 0.50 (iii) 9.0

Chapter 3, Section I : 9—Page 22

A

1 (b) 2.70 gm. per c.c. **3** (b) 8.0.

B

1 5 gm. per c.c. **2** 52.5 or 53. gm. **3** 268 c.c. **4** 62.5 or 63. lb. per cu. ft. **5** 64. lb. **6** 20.3 cu. ft. **7** 4.87 **8** 54.1 c.c. **9** 800 or 8×10^2 gm. **10** 0.068 **11** 0.59 cu. ft. **12** 1781.3 or 18×10^2 lb. **13** 7.64 gm. per c.c. **14** 0.8722 **15** 0.80 **16** 72.8 gm. **17** 8.5 gm. per c.c. **18** (a) 19.5% (b) 13.4% **19** 0.42 c.c. **20** 5.9 or 6. gm. per c.c. **21** 9.9 gm. per c.c. **22** 8.7 gm. per c.c. **23** 0.9 gm. per c.c. **24** 1.18 gm. per c.c.

Chapter 4, Section I : 15—Page 32

A

1 (b) (i) 100 gm. (ii) 790 gm. **3** (c) (i) 2.6 gm. (ii) 4.3 c.c

B

1 (a) 30 gm.; (b) 162.5 lb. **2** (a) 68 gm.; (b) 625.0 lb. **3** (a) 25 ml. (b) 0.40 cu. ft. **4** 10.5 **5** (i) 7.14 (ii) 70 c.c **6** (i) 2.5 (ii) 0.096 cu. ft. (iii) 156 lb. per cu. ft. **7** (i) 105.9 gm. (ii) 8.30 gm. per c.c. **8** 1.30 **9** (i) 5.36 (ii) 0.73 **10** 8.90, 0.840 **11** 32.0 gm. **12** No **13** 120 gm. **14** 0.9 gm. per c.c. **15** 156. or 1.6×10^2 lb. **16** 36.6 or 37. gm. **17** 11.7 c.c. **18** 0.90 gm. per c.c. **19** 1.3 **20** 18.8 or 19. cm. **21** 20.4 or 20 cm. **22** 100 gm. **23** 187.5 or 188. c.c. **24** 0.21 **25** $\frac{1}{3}$ **26** 14. cm.

Unit II—Sound

Chapter 6, Section II : 9—Page 61

A

5 (b) 1100 ft. per sec. **9** 1150 ft. per sec. **10** (a) 1100 ft. per sec.

B

1 (a) 3.75 cm.; (b) 15 cm. **2** .67, .67 sec. **3** (a) 1170 or 11.7×10^2 ft. per sec.; (b) 288 m. per sec. **4** (a) 320 v.p.s.; (b) 667 v.p.s. **5** (a) 1.50 ft.; (b) 56.0 cm. **6** (a) 1099, 1055, 1135 ft. per sec.; (b) 335, 321.8, 345.8 m. per sec. **7** (a) 15°C.; (b) 6.7°C. **8** 5595 ft. **9** 1.33 m. **10** 259 v.p.s. **11** (a) 357 m. per sec.; (b) 42°C. **12** (a) 56.5 ft. **13** 22.6 sec. **14** 750 m.p.h.

Chapter 7, Section II : 18—Page 71

A

6 (b) (i) 750 v.p.s., (ii) 100 v.p.s.; (c) (i) 208.3 or 208 v.p.s. (ii) 50 v.p.s.

B

1 (a) 960, 1920, 7680 v.p.s.; (b) 240, 60, 15 v.p.s. 2 240 v.p.s. 3 320 r.p.m. 4 150 teeth 5 256, 320, 384, 512 v.p.s. 6 900, 225, 675 v.p.s. 7 587 v.p.s. 8 25, 80, 35 cm. 9 1080, 270 v.p.s. 10 312 v.p.s. 11 400, 2500 gm. 12 384 v.p.s. 13 160 v.p.s.

CHAPTER 8, Section II : 25—Page 79

A

2 (a) (i) 48 in. (ii) 1200 ft. per sec.; (b) 24 in.

B

1 (a) (i) 5 ft. (ii) 1 ft.; (b) 1100 ft. per sec. 2 1:2 3 320 v.p.s. 4 11.9 in., .302 m. 5 15.5°C. 6 33.3°C. 7 18.8 cm. 8 4 beats per sec. 9 486 or 474 v.p.s.

CHAPTER 9, Section II : 34—Page 93

A

7 1781 ft.

Unit III—Heat

CHAPTER 11, Section III : 4—Page 114

A

4 4×10^{-3} lb.

CHAPTER 12, Section III : 11—Page 124

B

1 59, 392, —76, —459.4°F. 2 37.8, 176.7, —140, —45.6°C. 3 (a) —40°; (b) 320° 4 (a) (i) 330, 250° K. (ii) 25, —36° C.; (b) (i) 309.7, 255.2, °K. (ii) 212, —459.4°F.

CHAPTER 14, Section III : 32—Page 160

A

2 (b) (i) 350. cal., (ii) 5328 B.T.U., (iii) 179.4 cal. 4 (b) 0.087. 7 4000, 1600, 8400 cal. 9 (a) 27,000 cal.; (b) 8100 cal.; (c) 21,700 cal.

B

1 100,000 or 10×10^4 cal. 2 39,000 or 39×10^3 B.T.U. 3 91,000 or 91×10^3 cal. 4 6000 or 60×10^2 B.T.U. 5 1320 or 13.2×10^2 cal. 6 101 cal. 7 56.3 gm. 8 40°C. 9 0.104 10 0.0933. 11 0.21 12 0.031 13 292.6 or 293 gm. 14 204.3 or 204 gm. 15 12.8 or 13°C. 16 0.44 17 1250 or 12.5×10^2 gm. 18 187.5 or 188 gm. 19 208.3 gm. 20 80 cal. 21 78 cal. 22 82 cal. 23 0.50 24 27 gm. 25 46.6 or 47°C. 26 530 or 5.3×10^2 cal. 27 541 or 5.4×10^2 cal. 28 534 cal. 29 40°C. 30 53°C. 31 3640 cal. 32 0.112 or 0.11 33 121 or 1.2×10^2 gm.

Unit IV—Light

CHAPTER 16, Section IV : 8—Page 182

A

5 (d) 2 in. 7 (b) 8.3 min.

B

1 30 ft. 2 0.8 in. 3 148 or 1.5×10^2 m. 4 1.3 sec. 5 5.87×10^{12} miles, 9.46×10^{12} km. 6 52.8×10^{12} miles 7 4.3 years.

CHAPTER 17, Section IV : 20—Page 194

A

5 (a) 7.

B

1 (i) 10 o'clock (ii) 5.45 o'clock 4 (a) (i) 50 cm. (ii) 60 cm. (iii) 90 cm. (iv) $\propto$ (v) —60 cm. 5 —9.23 in. 6 3 ft. 7 4 in. 8 4.3 ft. 9 3 in. 10 36 cm. 11 —4.5 in. 12 —8.6 cm. 13 20 in. 14 2.2 in.

CHAPTER 18, Section IV : 34—Page 211

A

2 (c) 124,000 miles per sec.; (d) 2.47 5 (b) glass 7 (b) water 9 (d) 6.7 dioptres.

B

1 1.20 2 479×10^2 miles per sec. 3 (i) 35° (ii) 28° (iii) 20° 4 $\angle i = 48.5°$ $\angle D = 37°$ 5 One with critical angle of 30° 6 (a) (i) 50 cm. (ii) 60 cm. (iii) 90 cm. (iv) $\propto$ (v) —60 cm. 7 —9.2 in. 8 5 cm. 9 9 metres 10 80 $\times$ 11 32 in. 12 24 cm. 13 6 in. 14 24 cm. 15 —20 cm. 16 140, 12.7 cm. 17 (i) 0.9 in. (ii) 11 $\times$ 18 (a) 5.5 in.; (b) 36 in. x 60 in.

CHAPTER 19, Section IV : 43—Page 225

1 (c) 7.3×10^{14} v.p.s.

CHAPTER 20, Section IV : 50—Page 235

3 (a) 3.1 in.; (b) 1.5 in. 6 (c) (i) 8.3 $\times$ (ii) 6.7 $\times$ (d) (i) 25 mm. (ii) 20 mm. 7 (b) 160 $\times$ 9 (d) 192 cm.

Unit V—Magnetism and Electricity

CHAPTER 25, Section V : 39—Page 293

A

1 (b) 22 volts 4 (c) (i) 90 ohms (ii) 1.2 amp. (iii) 60, 48 volts; (d) (i) 13 ohms (ii) 5.5, 2.8 amp. 6 (b) 14 ohms.

B

1 12 ohms 2 212.5 or 21 $\times$ 10 volts 3 3.3 amp. 4 (a) 0.12 amp.; (b) 11.9 or 12 volts and 0.06 volts 5 (a) 22 ohms; (b) 5.5 ohms 6 (a) 41.3 ohms; (b) 0.333 amp.; (c) 2.66 amps. 7 (b) 6 volts; (c) 0.9 ohm 8 16.7 or 17 ohms. 9 (a) 3.4 ohms; (b) 3.3 amp.; (c) 1.7 amp. 10 0.2 amp. 11 (a) 2.4, 1.6 amp.; (b) 18 volts.

CHAPTER 26, Section V : 47—Page 302

B

1 (a) 3.55 gm.; (b) 12.1 gm. 2 (a) 9.5 gm.; (b) 32 gm. 3 (a) 2.4 gm. (b) 0.30 gm. 4 0.003 amp. 5 1.26 amp. 6 0.02 amp. 7 (a) 0.18 amp.; (b) 0.0028 gm 8 0.002 cm. 9 3.95, 0.37 gm. 10(a) 2 amp.; (b) 15 hr.

CHAPTER 27, Section V : 56—Page 315

B

1 (a) 0.08 ohm; (b) 0.008 ohm; (c) 0.0008 ohm, 20.002 ohms 3 (a) 115 ohms; (b) 1240 ohms; (c) 12490 ohms 4 9998 ohms.

CHAPTER 28, Section V : 69—Page 329

B

1 80 turns 2 2200 volts 3 9.2 volts 4 220 volts 5 400 turns 6 (i) 96 turns (ii) 64 turns (iii) 48 turns (iv) 32 turns.

CHAPTER 29, Section V : 76—Page 338

B

1 (a) 24×10^6 volts; (b) 1/2000th; (c) greatly diminished 2 (a) 50:1; (b) (i) 50 times (ii) 2500 times 3 1650 watts 4 5 amp. 5 220 volts 6 (i) 0.498 h.p. (ii) 372 watts (iii) 0.372 kw. 7 1650 watts 8 No. 9 6 cents 10 4.3 cents 11 9.7 cents 12 $1.12 13 6 cents.

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